NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN ANALYSIS OF OPERATIONAL EMPLOYMENT FOR THE SH-60B LIGHT AIRBORNE MULTI-PURPOSE SYSTEM MK III HELICOPTER

by

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June 1995

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE June 1995

3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE AN ANALYSIS OF OPERATIONAL EMPLOYMENT FOR THE SH-60B LIGHT AIRBORNE MULTI-PURPOSE SYSTEM MK III HELICOPTER

5. FUNDING NUMBERS

6. AUTHOR(S) Unger, Kenneth Lee Curtis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

The SH-60B Light Airborne Multi-Purpose Systems (LAMPS) Mk III helicopter is currently employed with few or no weapon systems which preclude it from being a multi-mission capable weapon platform in a littoral warfare scenario. This thesis provides a decision aid for effectively configuring a weapon load for a variety of weapon systems available to the SH-60B to allow it to be truly multi-mission capable.

An introduction to the SH-60B LAMPS Mk III helicopter is provided to assist the reader in understanding the helicopter's capabilities. The SH-60B helicopter's missions and weapons are discussed in detail and the decision making tools and techniques used in this thesis are presented to the reader. A configuration decision model is constructed using utility of a weapon and the configuration cost of the weapon.

A decision model is developed for determining the weapon configuration for the SH-60B if the mission assigned to the helicopter is not known when the helicopter is configured with weapons. The model incorporates the helicopter's weapons configuration when the assigned mission is known. The model provides a recommended weapon configuration for the SB-60B helicopter based on weapon effectiveness and configuration cost.

14. SUBJECT TERMS SH-60B; LAMPS Mk III; Mission; Weapon Configuration; Decision

15. NUMBER OF PAGES 130

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

Approved for public release: distribution is unlimited

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Submitted in partial fulfillment
of the requirements for the degree

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 1995

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ABSTRACT

The SH-60B Light Airborne Multi-Purpose System (LAMPS) Mk III helicopter is currently employed with few or no weapon systems which preclude it from being a multi-mission capable weapons platform in a littoral warfare scenario. This thesis provides a decision aid for effectively configuring a weapons load for a variety of weapon systems available to the SH-60B to allow it to be truly multi-mission capable.

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EXECUTIVE SUMMARY

The SH–60B Light Airborne Multi–Purpose System (LAMPS) Mk III helicopter is currently employed with few or no weapon systems which preclude it from being a multi–mission capable weapons platform in a littoral warfare scenario. Currently, the SH–60B LAMPS Mk III can be employed with torpedoes and only several in the entire fleet can carry the Penguin missile. With new weapon systems becoming available to the SH–60B, an effective weapons load is required to ensure sufficient and timely firepower for a constantly changing littoral environment.

A brief introduction to the SH–60B LAMPS Mk III helicopter is provided to assist the reader in understanding the helicopter's capabilities. The SH–60B helicopter's missions are defined to incorporate the operational realm of the helicopter's capabilities. This thesis is primarily concerned with effectively configuring the helicopter with the following weapon systems: Hellfire missiles, Penguin missiles, 2.75 inch rockets, a forward firing gun, torpedoes, and/or 500 pound bombs. In addition to these weapon systems, the helicopter is considered to have a fourth weapons station, one more than current design allows, to be used in weapon configurations with the weapons listed above.

This thesis presents a decision model to determine which of the aforementioned weapon systems are to be loaded on to an SH–60B in a littoral warfare scenario if the assigned mission is not known when the helicopter is configured with the weapons. The missions assigned to the SH–60B are directly related to a particular type of threat or

threats. This in turn influences the type of weapon system to be used for a particular mission. The decision model uses the utility of a weapon, a type of weapon effectiveness, and the configuration cost of the weapon to provide a recommended weapon configuration. The utility of a weapon was determined using indifference probabilities for each mission type assigned to the SH–60B. It essentially determines the decision maker's priority of weapons to load on to the helicopter for a given type of mission. The configuration cost is the dollar cost of the expendable weapon in each weapon system. This thesis used dollar cost, but it should be understood that dollar cost is only one of any reasonable cost values, particular to a given problem, that may be used in this model.

Since littoral warfare environments change almost continuously, it is impossible to determine or define a weapons mix that will be effective in all situations. The thesis provides a decision model and solves an example scenario based on the author's experience and judgement. The model developed in the thesis allow the decision maker to control all aspects of the model, most importantly, the weapon systems, the operational mission assignments, the utility of the weapon system for a given mission assignment, and the “cost” of a weapon system. Once the decision maker has decided on the utility values of the weapons and the probability of success of a weapon for a given mission, a simple spreadsheet will solve the model, and the decision maker can graph the results and determine the best weapon configuration for the current situation.

ACKNOWLEDGMENT

The author wishes to thank Professor Mike Sovereign and Commander Steve Meyers for their abundant patience, expertise, and guidance; Professor Kneale Marshall for his friendship, wealth of knowledge, and focus for completing this project; Lieutenant Commander Jack Keane for being a constant friend and providing support; Lisa Puzon whose endless assistance allowed the fruition of this project; and finally this thesis is dedicated to my wife Véronique for her love, support, patience and understanding, thank you.

I. INTRODUCTION

As the new world order emerges, the United states, as a superpower, must continue to provide leadership and support for evolving and developing countries. The United States, in order to maintain its global interests, regional stability, and political influence of events, must maintain a forward military presence, coupled with a power projection capability [Ref. 1]. With the downsizing of the military and the steadily reducing military budget, a more efficient and effective military capable of fulfilling its post cold war missions is required to strengthen the new world order.

As the U.S. national military strategy has shifted from a global to a regional threat, future conflicts in a littoral region are a logical focus. The U.S. Naval forces in littoral environments provide the unique capabilities of an unobtrusive forward presence, strategic deterrence, sea control, crisis response, and power projection [Ref. 2:p. 1]. In the littoral conflict, battlespace (e.g., the sea, air and land environment where operations are conducted) dominance is vital and key to the successful conclusion of any military action [Ref. 2:p. 8]. Sea control and surveillance of the littoral battlespace are a primary concern throughout the conflict. This concern necessitates the improvement of battlespace dominance, and the effective employment of available sensors. Two of the most versatile sensor systems available are (1) the SH-60B Light Airborne Multi-Purpose System (LAMPS) MK III weapons system, consisting of the Sikorsky SH-60B helicopter and a

LAMPS MK III system configured ship, and (2) an Unmanned Aerial Vehicle (UAV) with multiple sensor system payloads [Ref. 3].

A. PURPOSE OF THESIS

In one aspect of the littoral warfare scenario, friendly forces must be protected from unfriendly small attack boats, patrol boats, and ships, as well as being kept aware of enemy movement on and over the battlespace. The battlegroup commander must be able to project an effective force with sufficient firepower to achieve the desired goal, in a constantly changing littoral environment. The SH-60B Light Airborne Multi-Purpose System (LAMPS) MK III weapons' system is one asset available to help accomplish this task. With an effective weapons' configuration, the SH-60B Light Airborne Multi-Purpose System (LAMPS) MK III becomes a versatile and formidable weapons system. The ability to configure the SH-60B helicopter effectively is necessary in order for it to be a useful asset to the battlegroup commander. This thesis provides a basis for a decision aid to allow for effective weapons configurations for the SH-60B helicopter.

The remainder of **Chapter I** outlines the SH-60B background, defines the operational capabilities, and addresses the meaning of "multi-mission," and describes the operational decisions for the SH-60B helicopter. **Chapter II** discusses the various missions and weapon configurations of the SH-60B helicopter. **Chapter III** describes the decision modeling tools, their uses, and how the decision maker can utilize them. **Chapter IV** describes the decision model and provides a solution for a sample problem. **Chapter V** discusses the thesis conclusions and recommendations for further study.

B. SH-60B LAMPS MK III

In the mid-1970s, the United States Navy (USN) began a program that would support battle group mission requirements in antisubmarine warfare (ASW) and antisurface (ASUW). The Light Airborne Multi-Purpose System (LAMPS) MK III was the result, and a variant of the Sikorsky-built H-60 helicopter was the airframe designed to carry the airborne portion of the system deploying on board fast frigates (FFGs), destroyers (DDGs), and the Aegis cruisers (CGs). Together they comprise the SH-60B LAMPS MK III system, which entered the fleet in 1984. From their introduction to the fleet until the present day, the weapon systems and mission definitions have undergone continuous change. These changes, coupled with the unique flexibility of the SH-60B, have allowed it to do a wide variety of missions, well beyond those initially envisioned.

The earliest "vision" of the LAMPS was a formidable ASW capability and an over-the-horizon search and strike capability. This "vision" filtered down to define the SH-60B LAMPS MK III missions. Its primary mission is ASW, with a major secondary mission of anti-ship surveillance and targeting (ASST), and minor secondary missions including search and rescue (SAR), medical evacuation (MEDEVAC), vertical replenishment (VERTREP), naval surface fire support (NSFS), and communication relay (CommRelay). These have further evolved into ten basic types of missions: (1) ASW, (2) ASST, (3) Reconnaissance, Surveillance, and Target Acquisition (RSTA), (4) CommRelay, (5) NSFS, (6) combat search and rescue (CSAR), (7) mine warfare countermeasures (MCM), (8) electronic countermeasures (ECM), (9) ship boardings, and (10) Utility or "Other." In the present time, and in view of the volatility of the world's

politics, any one of these missions may be the "primary" mission, with multiple secondary missions on any given day. The SH-60B when initially designed, with respect to weapon systems, was only able to launch torpedoes. Today, with the Block I and II upgrade packages, the SH-60B is capable of firing or launching the Penguin missile, the MK-50 torpedo, and a 7.62 mm M-60 machine gun. In the near future, weapons add-ons could see a Hellfire missile system, 2.75 inch rockets, a forward firing gun, and a door-mounted Gatling gun incorporated into the SH-60B. With the main focus of requirements changing from an open ocean warfare strategy to a littoral warfare strategy, and in view of the military downsizing, a capable armed SH-60B to deal with this new threat environment is not only desirable, but necessary.

C. SH-60B OPERATIONAL CAPABILITIES

The Chief of Naval Operations (CNO) has defined the mission statement of the SH-60B helicopter as:

> Provide SH-60B helicopter detachments to operate offensively in a high density anti-submarine and anti-surface environment as an integral part of a CV {Carrier} Battlegroup, Amphibious Assault Group, or Underway Replenishment Group, in conjuction with surface ships configured with and without LAMPS MK III weapon system. Additionally, detachments must operate defensively in high density anti-air environments. [Ref.4]

The operational capabilities and sub-capabilities for the SH-60B helicopter are defined for the Anti-Air Warfare (AAW), Amphibious Warfare (AMW), Anti-Surface Ship Warfare (ASUW), Anti-Submarine Warfare (ASW), Command, Control, and Communications (CCC or C^3), Electronics Warfare (ELW), Fleet Support Operations (FSO), Intelligence

(INT), Logistics (NCO), Mine Warfare (MIW), Mobility (MOB), and Non-Combatant Operations (NCO) mission areas [Ref. 4]. These operational capabilities are incorporated into the ten missions types listed above, or are inherent in the effective operation of the helicopter itself. **Appendix A** contains specific descriptions of each operational capability and corresponding sub-capabilities for the SH-60B.

D. MULTI-MISSION DEFINITION

By definition the SH-60B LAMPS MK III is "multi-purpose." But what does this mean after 20 years of evolution? Initially, it meant it could do its primary and secondary missions to meet the needs of the Fleet in a cold war strategy. Today, this "multi-purpose" has transformed into "multi-mission," which requires it to perform a variety of missions, whether simple or complex (e.g., two or more different mission types), to meet the needs of the Fleet in both open ocean and littoral type strategies. The philosophy of the correct term to use has little meaning to the operators of the system. This thesis uses multi-mission and defines it as the performance of one or more mission types, simple or complex, performed independently and, if necessary, sequentially with each other. This constraint is not a limitation of the aircrew or the LAMPS MK III system, but a scoping restraint for the purposes of this thesis. Given the multi-mission definition above, and an SH-60B LAMPS MK III with the capability to carry a variety of forward firing weapons, the primary research question is "How can the multi-mission capabilities of the LAMPS MK III be effectively utilized in the envisioned tactical environment?" The answer has always been complex due to the many mission assignments within the battle group which

force prioritization of missions. Now, the solution has the added dimension of weapon load-out on the SH-60B. For the most effective use of the LAMPS MK III system, the multi-mission concept must be addressed and defined for each operational environment. Since the operational environment is dynamic, the multi-mission definition must change to adapt to each new environment.

E. OPERATIONAL DECISIONS

The operational decisions to be made, with respect to this thesis, are (1) what should be the SH-60B's weapons configuration if the mission assigned is not known when the weapons configuration is done, and (2) what should be the SH-60B's weapons configuration given an assigned mission. The first decision is based on the author's experience and the fact that the weapons loading procedure is very time consuming, and not able to be done on a moment's notice. The author's experience includes being an SH-60B pilot for seven years, and having performed the duties of the battlegroup LAMPS Element Coordinator (LEC) for two battlegroups. The first decision is also the most common situation that would occur in a littoral warfare scenario, due to the helicopter being (1) airborne on a routine patrol mission (a common standard procedure) when a new mission is assigned, due to a changing threat environment in the battlespace, requiring weapons or (2) on alert status on the ship's flight deck where a time critical response would preclude any weapons' re-configuration. The second decision is the ideal case where the mission is known before weapons are loaded on the helicopter and there is ample time to configure the helicopter as required to meet the mission's weapons

thesis will address both of these decisions in detail and provide a solution for a sample problem.

F. SUMMARY

With the introduction of the LAMPS MK III system, ASW and ASST were the primary missions. As the national military strategy changed, the LAMPS MK III system acquired more missions, and those missions have broadened in scope. There are presently twelve operational capabilities that are defined for the SH-60B [Ref. 4]. From these operational capabilities, numerous types of missions may be defined. With the many possible missions to be assigned to the LAMPS MK III, its multi-mission capabilities must be defined and examined in each specific operational environment to most effectively utilize the weapon system. Together with its multi-mission capabilities and the operational decisions made, the LAMPS MK III becomes a formidable and flexible weapons system available to the battlegroup commander.

II. HELICOPTER MISSIONS AND WEAPONS

For the purpose of this thesis, the CNO defined operational capabilities will be transformed into nine mission types: (1) ASW, (2) ASST, (3) RSTA, (4) NSFS, (5) CSAR, (6) ECM, (7) MCM, (8) Boarding, and (9) "Other." The CommRelay mission type is incorporated into the "Other" mission defined by this thesis. The operational capabilities were "compressed" into nine mission types to reflect a more everyday type operational tasking order. Although multiple operational and sub-operational capabilities are contained in the nine mission types listed above, the following statements provide a clearer idea of how those capabilities were incorporated into the mission types. **Appendix A** provides a listing of all the unclassified capabilities and sub-capabilities for each mission type as defined in Reference 4. The Anti -Air Warfare (AAW), Non-Combatant Operations (NCO), Mobility (MOB), and Command, Control, and Communications (C^3) operational capabilities are inherent in the basic operation and maintenance of the helicopter. The Amphibious type (AMW) operational capabilities are incorporated into the Naval Service Fire Support (NSFS) mission type. The Anti-Surface Warfare (ASU) and Intelligence (INT) operational capabilities are divided between the Anti-Ship, Surveillance, and Targeting (ASST) and the Reconnaissance, Surveillance, and Target Acquisition (RSTA) mission types. The Mine Warfare (MIW) operational capabilities are incorporated into the Mine Countermeasures (MCM) mission type. The Fleet Support Operations (FSO) operational capabilities are incorporated into the Combat

Search and Rescue (CSAR) mission type. The NCO operational capabilities are contained in the Boarding mission type. Finally, the Logistics (LOG) operational capabilities are contained in the "Other" mission type. Although these are the major relationships that occur among the operational capabilities and the mission types, it is by no means absolute and is used only for the purposes of this thesis. The weapon systems available to the SH-60B will include the Penguin missile, the Mk-50 torpedo, the Hellfire missile, 2.75 inch rockets, a forward firing gun, and a door-mounted Gatling gun. The untested and unapproved weapon systems (i.e., the Hellfire missile, 2.75 inch rockets, a forward-firing gun, and a door-mounted Gatling gun) were added to reflect a more appropriate littoral warfighting capability. These modified definitions and additional weapon systems are thought necessary to be effective in the littoral and coastal warfare environments. It should be understood that these changes are for the purpose of this thesis only, and are not approved or recommended by the CNO, Naval Air Systems Command (NAVAIR), or the SH-60B Program Manager's Office.

A. OPERATIONAL MISSIONS

As stated above, the operational missions of the SH-60B will be defined as the nine mission types listed above: (1) ASW, (2) ASST, (3) RSTA, (4) NSFS, (5) CSAR, (6) ECM, (7) MCM, (8) Boarding, and (9) "Other." The ASW mission will be considered as the autonomous ability to detect, localize, track, and attack enemy submarines. The ASST mission is defined as the ability to detect, localize, track, and pass targeting information on surface contacts. The RSTA mission is defined as the ability to detect, localize, track, pass

targeting information, and attack hostile surface contacts. The NSFS mission is defined as the ability to observe selected targets, direct fire support for naval gunfire and artillery, and participate in firing on selected targets. The CSAR mission is defined as the ability to conduct combat rescue in approved operating environments (see page A-74 of **Appendix A**), and provide necessary suppression fire when required. The ECM mission is defined as the ability to launch chaff and/or any available decoys to assist a ship in defending itself against a missile attack. The MCM mission is defined as the ability to localize, mark, and destroy mines, and assist an Explosive Ordnance Destruction/Sea, Air, Land (EOD/SEAL) team in the same. The Boarding mission is defined as the ability to track, perform reconnaissance, and assist inspection teams in the boarding of suspect ships. The "Other" mission is defined as the ability to perform all requested battlegroup logistics, passenger and mail transfer, and any other reasonable mission assigned to the LAMPS Mk III necessary for battlegroup or Surface Action Group (SAG) operations. These mission's definitions are assumed to incorporate the operational capabilities and sub-capabilities, where appropriate similarities exist, defined in Reference 4.

B. WEAPON AND SENSOR SYSTEMS

A variety of weapon and sensor systems are available to the SH-60B. For the purposes of this thesis, weapon and sensor systems that are currently employed on the SH-60B, and those that could reasonably be added, will be addressed. The following sixteen weapons and sensors will be considered available to the SH-60B: (1) radar, (2) Magnetic Anomaly Detector (MAD), (3) sonobuoys, (4) self defensive chaff, (5) flares,

(6) Forward Looking Infrared Radar (FLIR), (7) ship decoy chaff, (8) Low Light Television (LLTV), (9) laser designator, (10) 7.62 mm door gun, (11) Mk-50 torpedo, (12) Mk-82 bombs, (13) Hellfire missiles (HF), (14) 2.75 inch rockets, (15) a Forward Firing (FF) gun, and (16) the Penguin missile. Currently, the SH-60B has three weapon stations available to it, one forward left, one aft left, and one aft right. The possibility exists to add a fourth weapon station. To identify these weapon stations with greater ease, the following labeling convention will be adopted and used throughout the remainder of this thesis. The forward stations are designated as "primary" and the aft stations are designated "secondary". **Figure 1** provides a sketch of the general location and naming convention for each weapon station of the SH-60B as modified for this thesis. It is assumed that the gross weight limitations and center of balance restrictions on the SH-60B are not violated with the addition of the fourth weapon station and a reasonable mix of weapons and sensors defined above.

Since the SH-60B incorporates many of these systems in its design, the SH-60B in this thesis will have a "BASE" configuration which will consist of a radar, MAD, sonobuoys, self-defensive chaff, flares, ship decoy chaff, a FLIR, a LLTV, a laser designator, and a 7.62 mm door gun, in addition to the fourth weapon station. Although it is unlikely to carry all these sensors and systems simultaneously, it is assumed that when they are required or needed, they are available and the helicopter does not need to return to its ship to on-load them.

Because of the basic geometry and location of the weapon stations, differences in operational capabilities exist among each station. For the purpose of this thesis, the

primary stations will be used only for the Hellfire missile, the Penguin missile, 2.75 inch rockets, and a forward firing gun. The Penguin missile has an additional constraint of only being allowed to occupy the left primary weapon station. A deliberate lack of specificity

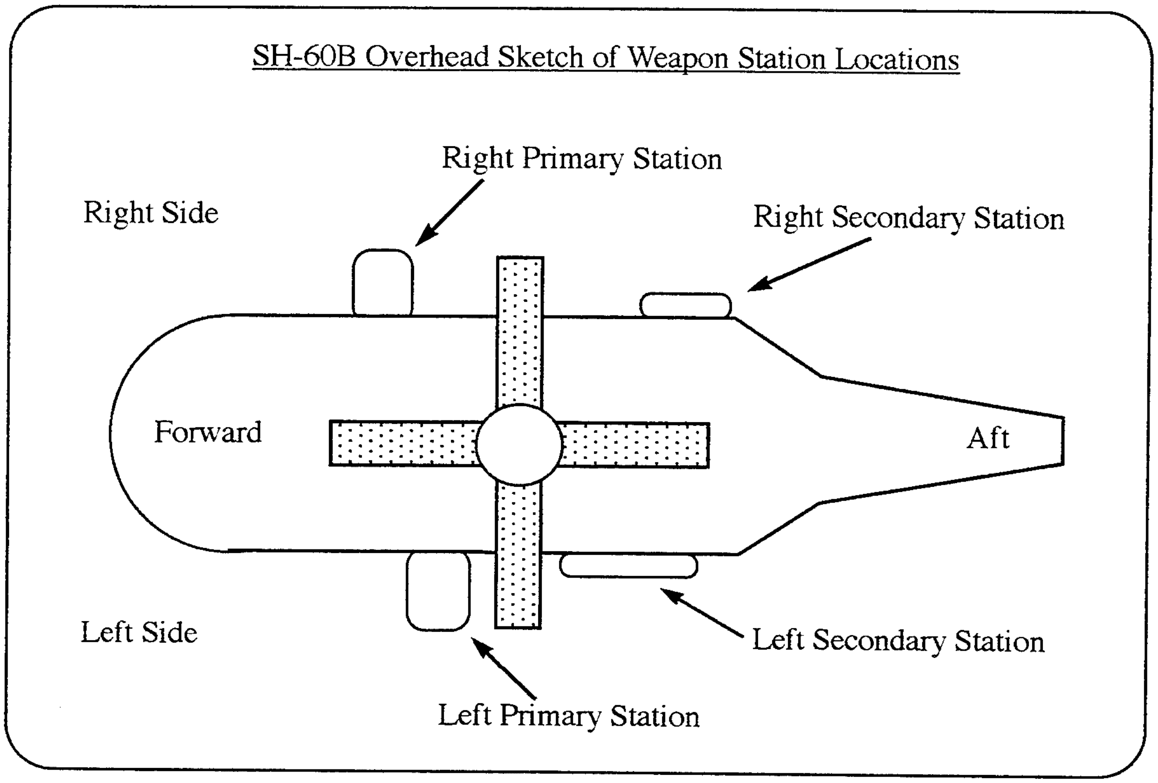

Figure 1. SH-60B Weapon Stations Locations and Naming Conventions

for the latter two weapon systems, the 2.75 inch rockets, and a forward firing gun, is appropriate since the exact weapon is not the issue of importance, but the availability of such a weapon to complete an assigned mission is of concern. The Penguin and Hellfire missiles are specific because they are either approved for use, or undergoing testing. The secondary stations will be used for torpedoes and bombs only. **Table 1** shows an example possible weapons load-out schemes. Weight limitations are considered nonrestrictive for

this example due to the assumption of no gross weight limitation violations and using realistic weapons load-outs (e.g., not overloading weapon stations).

TABLE 1. WEAPON LOAD-OUT COMBINATIONS

Weapon	Primary Weapon Station Left / Right	Secondary Weapon Station Torpedoes only Left/Right	Secondary Weapon Station Torpedo and Bomb Left/Right	Secondary Weapon Station Bombs only Left/Right
Hellfire	4/4	1/1	1/1	1/1
Hellfire/ Rockets	4/19	1/1	1/1	1/1
Hellfire/FF Gun	4/500 rds	1/1	1/1	1/1
Penguin/ Hellfire	1/4	1/1	1/1	1/1
Rockets	19/19	1/1	1/1	1/1
FF Gun	0/500 rds	1/1	1/1	1/1
Penguin	1/0	1/1	1/1	1/1

. The first column lists those combinations of weapons available to the primary weapon stations with the quantity of those weapons shown divided between the left and right weapon stations, listed in column two. The last three columns list those combinations and quantities of weapons available to the secondary weapons station. The operational use of the primary and secondary weapon stations are independent of each other.

C. WEAPON CONFIGURATIONS

With the operational mission definitions and the weapon systems available to the SH-60B, a list of desired weapon system for each mission type can be constructed. The availability of such a list would be particularly useful when deciding a helicopter configuration for an assigned mission. Table 2 shows an example of such a list. This type of table could easily be changed to meet the needs or required characteristics of a helicopter's mission or to allow for changes in the weapon systems available to the helicopter.

TABLE 2. MISSION WEAPON SYSTEM REQUIREMENTS

Mission	Weapon Systems Required for a Mission
ASW	sonobuoys, torpedoes, MAD, radar, bombs, ESM
ASST	radar, ESM, FLIR, LLTV
RSTA	radar, ESM, FLIR, LLTV, Laser designator, rockets, Hellfire, Penguin, FF Gun
NSFS	radar, FLIR, LLTV, laser designator, FF Gun, ESM
CSAR	radar, FLIR, FF Gun, Hellfire, rockets, ESM
ECM	ESM, decoy chaff, radar
MCM	FLIR, radar, LLTV, effective door gun
Boarding	FLIR, LLTV, FF Gun, effective door gun
"Other"	various

Since only certain weapons can be loaded on certain weapon stations, 44 feasible weapon configurations can be constructed. The configurations that are feasible are those where the Hellfire missiles, rockets, FF Gun, and the Penguin missile are installed only on the primary weapon stations and torpedoes and bombs are installed only on the secondary

weapon stations. It is also necessary that the primary and secondary weapons are independent and do not interfere with each other.

Table 3 lists the 44 feasible configurations. The primary weapons are listed prior to the secondary weapons for the appropriate weapon configurations. The following key aids in interpreting the meaning of the table:

- "BASE" : the "BASE" helicopter configuration defined above
- "HF" : Hellfire missiles
- "R" : 2.75 inch rockets
- "P" : the Penguin missile
- "FF" : the forward firing gun
- "T" : torpedoes
- "B" : 500 lb. bombs
- "+" : indicates the addition of weapon to a weapon station(s).

TABLE 3. ALL FEASIBLE WEAPON CONFIGURATIONS

BASE	BASE+R+T	BASE+HF+R+B	BASE+R+P+T
BASE+HF	BASE+R+B	BASE+HF+R+T+B	BASE+R+P+B
BASE+R	BASE+R+T+B	BASE+HF+P	BASE+R+P+T+B
BASE+P	BASE+P+T	BASE+HF+P+T	BASE+R+FF
BASE+FF	BASE+P+B	BASE+HF+P+B	BASE+R+FF+T
BASE+T	BASE+P+T+B	BASE+HF+P+T+B	BASE+R+FF+B
BASE+B	BASE+FF+T	BASE+HF+FF	BASE+R+FF+T+B
BASE+T+B	BASE+FF+B	BASE+HF+FF+T	BASE+P+FF
BASE+HF+T	BASE+FF+T+B	BASE+HF+FF+B	BASE+P+FF+T
BASE+HF+B	BASE+HF+R	BASE+HF+FF+T+B	BASE+P+FF+B
BASE+HF+T+B	BASE+HF+R+T	BASE+R+P	BASE+P+FF+T+B

The order of the listing or the ordering of weapons within each configuration is not significant. Each weapon in a particular configuration occupies one weapon station, therefore a maximum of four weapons for any configuration is the limit.

Since mission requirements can be related to the required weapon systems, as shown in **Table 2**, and the helicopter configurations can be defined, as shown in **Table 3**, the operational decisions of (1) what should be the SH-60B's weapons configuration if the mission assigned is not known when the weapons configuration has already been completed, and (2) what should be the SH-60B's weapons configuration given an assigned mission can be addressed. The decision maker (e.g., the Officer-in-Charge (OIC) of a helicopter detachment or the ship's captain for matters pertaining to the helicopter) must be cognizant of the mission weapons requirements, **Table 2**, the feasible weapons configuration, **Table 3**, and the current tactical situation in order to make an informed operational decision. **Chapter III** outlines and explains the tools the decision maker needs and **Chapter IV** provides a detailed example, using these tools, of a sample SH-60B weapons configuration decision problem.

D. SUMMARY

By defining the operational missions in terms of the operational capabilities and sub-capabilities and limiting the number of missions to nine mission types, the battleforce commander has a simpler task of assigning missions to the SH-60B, from a real-world operating environment perspective. With the definition of these mission types, the next problem is configuring the helicopter to best fit its assigned mission. To allow for closer examination of the SH-60B weapon systems that are installed on the weapon stations, a "BASE" configuration of the SH-60B will always be considered as "standard" equipment for each flight. It should be understood that this "BASE" configuration does not provide

an optimal weapons mix for every mission assigned, however, for the purpose of this thesis, it is assumed that this configuration is not restrictive in any sense to the decision problem or the helicopter operation. In general, those weapon systems that attach to the weapon stations are more costly in both procurement and operation than those systems defined in the "BASE" configuration. The sensor and weapon systems in the "BASE" configuration are assumed to be either integral components to the helicopter or able to be launched by the helicopter.

Starting with this "BASE" configuration and adding various combinations of six types of weapons presented in this thesis, 44 feasible configurations were constructed. Feasible configurations are those where torpedoes and bombs are the only weapons allowed to be installed on the secondary weapon stations, and the remaining weapons are allowed to be installed only on the primary weapon stations. A feasible configuration is also constrained to one weapon system per station. Given the mission-type and weapon-configuration definitions, the question of which mission is best for a given configuration, and which configuration is best for a given mission, can now be addressed.

III. DECISION MAKING TOOLS

Defining the mission-weapon system requirements and constructing a feasible weapon configuration table, coupled with the ability to perform decision analysis, the decision maker can make informed decisions of helicopter configurations or operational mission assignments. "Decision analysis provides tools for quantitatively analyzing decision with uncertainty and/or multiple conflicting objectives [Ref. 5]." Decision analysis will be defined as the use of influence diagrams and decision trees, the use of suitable methods for measuring the outcomes, and preferences of the available choices or alternatives [Ref. 6:p. 3].

The decision making approach used by this thesis will introduce influence diagrams that allow the decision maker, usually the Officer-in Charge (OIC) of a helicopter detachment or the ship's captain for matters pertaining to the helicopter, to see the dependencies between various combinations of random events and decisions. Decision trees will be used to show the sequences of decisions and random events that can occur in all possible scenarios of the decision problem [Ref. 6:p. 11]. This type of approach is a natural progression in the following sequence: (1) defined operational capabilities for the SH-60B, (2) defined mission types from the operational capabilities of the SH-60B, (3) specify weapon systems and sensors available to the SH-60B, (4) designate a minimum subset of weapon systems and sensors to each mission type, (5) develop feasible weapon configurations from the available weapon systems, and (6) make reasonable and informed

decisions in the effective utilization of the SH-60B with respect to mission assignment and helicopter configuration. Although not discussed in this thesis, this progression has two more logical steps, (7) efficient flight scheduling for an operational mission, and (8) total operational costing for air vehicle comparisons.

The remainder of this chapter will define and explain the necessary concepts used in this thesis. The ideas and tools of decision modeling used in this thesis are influence diagrams, decision trees, perfect information, and the Pareto frontier.

A. ESSENTIAL ELEMENTS

Both influence diagrams and decision trees used in this approach use nodes, branches, and directed arcs as borrowed from network and graph theory. Three types of nodes are defined: (1) square nodes are decisions, called decision nodes, (2) round nodes are random events or quantities, called chance nodes, (3) diamond nodes are the results of the decision process, called result nodes. Each decision node has an associated decision set containing all possible decision outcomes for that particular decision, denoted by $\mathcal{C}$ (for all feasible configurations). Each random event has an associated random outcome set containing all possible outcomes for that particular event, denoted by some scripted letter such as $\mathcal{M}$ (for all mission types defined for the SH-60B). Finally, the set of all possible results for a particular decision model is denoted by $\mathcal{R}$. The construction of influence diagrams and decision trees is done in the chronological order of occurrence. For example, if a decision node is drawn, then all events that occurred prior to the decision node are written to its left and those events that occur after the decision are written to its right.

B. INFLUENCE DIAGRAMS

The influence diagram uses the three types of nodes and directed arcs to display the structure and dependencies of the decision problem. Directed arcs between two nodes indicate some type of dependence between those nodes. **Figure 2** shows the basic elements (i.e., the node and directed arc combinations) of an influence diagram [Ref. 6:p. 11]. In the figure, random events are denoted by X and Y, and decisions are

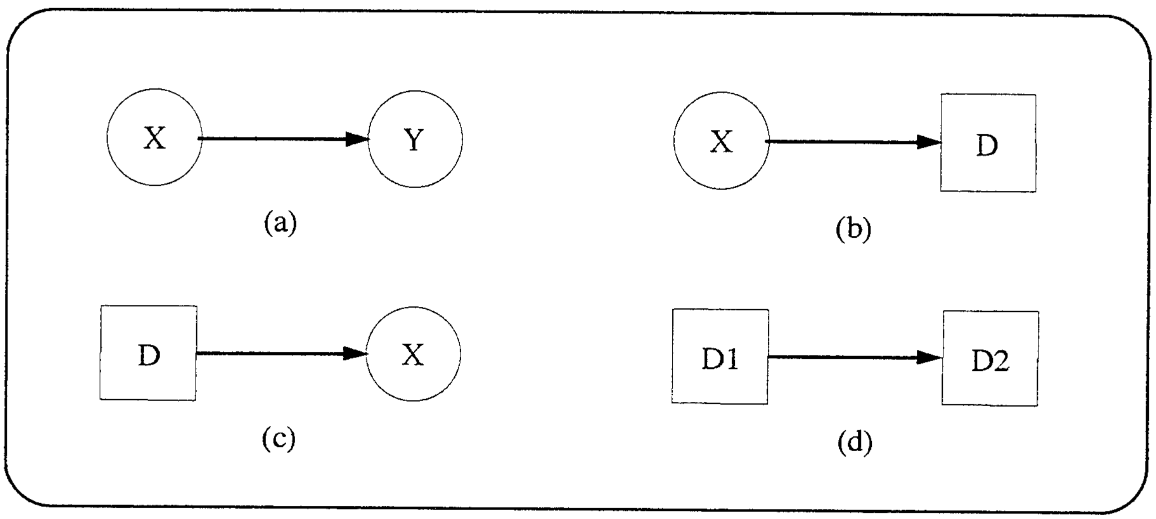

Figure 2. Influence Diagram Node/Directed Arc Elements

denoted by D, D1, and D2. Circles, in **Figure 2**, are chance outcomes and squares are decision processes. In part (a) of **Figure 2**, a directed arc connects two chance nodes, which are random events. This type of element indicates that the random events may be dependent, and the outcome of random event X is known before the probability distribution of Y is assessed. In part (b) of **Figure 2**, a directed arc connects a chance node to a decision, a directed arc connects a chance node to a decision node. This type of element indicated that the outcome of the random event X is known before the decision is

made, and decision D is probably influenced by that outcome. In part (c) of **Figure 2**, a directed arc connects a decision node to a chance node. This type of element indicates that decision D is made before the random event X occurs (i.e., the probability distribution is assessed), and the probability distribution of X may be dependent on the decision made. In part (d) of **Figure 2**, a directed arc connects two decision nodes. This type of element indicates that decision D1 is known before decision D2, and decision D2 may be influenced by decision D1. [Ref. 6:pp. 10-11]

Influence diagrams are used to help the decision maker and analyst visualize graphically how decisions, uncertain events, and outcomes are interrelated [Ref. 6:p. 95]. By design, they offer oversight of the probabilistic structure of the decision problem, show the time sequential order of events, decisions, and outcomes, and give insight to the interdependence of decisions and possible actions. Although they give no detailed information of the decision problem, they make three significant contributions. First, influence diagrams provide a framework where the decision problem structure and dependencies can be examined without formal mathematical or statistical notation and analysis. Second, influence diagrams can reduce large volumes of data into the portion of data essential and relevant to decision making. Finally, influence diagram complexity can be reduced by the direct use of algorithms and numerical techniques. [Ref. 6:pp. 95-97]

Figure 3 shows a generic example of influence diagram. The appropriate nodes are labeled in the figure. The influence diagram in **Figure 3** indicates the outcome of the random event F is known before decision D is made or the random event X occurs. The influence diagram indicates that the decision may be influenced by the outcome of F, and

the outcome of the random event X may have some type of dependence on the known

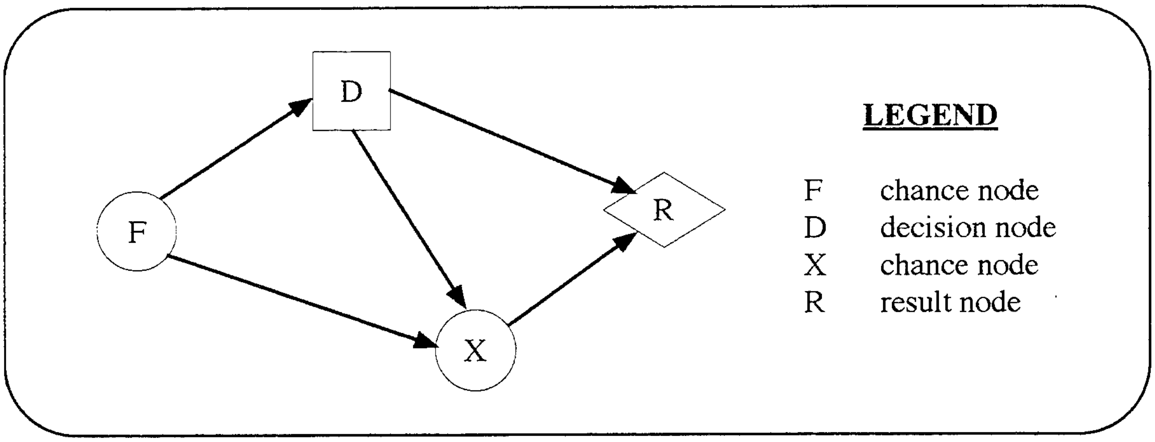

Figure 3. Example Influence Diagram

outcome of F. It also indicates that the decision is made before the random event X, and that decision may influence the outcome of X. Finally, the influence diagram indicates that the result R depends on decision D and the random outcome of X, but not explicitly on the outcome of F.

C. DECISION TREES

"Decision trees display the sequences of decision and random events that can occur in all possible scenarios of the decision problem [Ref. 6:p. 11]." Decision trees use the sets associated with the possible decisions, $\mathcal{C}$, random events, $\mathcal{M}$, and outcomes, $\mathcal{R}$ in its construction. Unlike the influence diagram, which does not incorporate the set information in its structure, the decision tree uses this set information to construct the branches of the tree. The number of branches emanating from each node is equal to the number of members in each node's respective data set. The decision tree uses the influence diagram's

chronological sequence of events in its construction. **Figure 4** shows a simple example of a decision tree drawn from the influence diagram in **Figure 3**. The following dialog explains how it was drawn. The chance node F has a defined set of possible outcomes $\mathcal{F}$ =

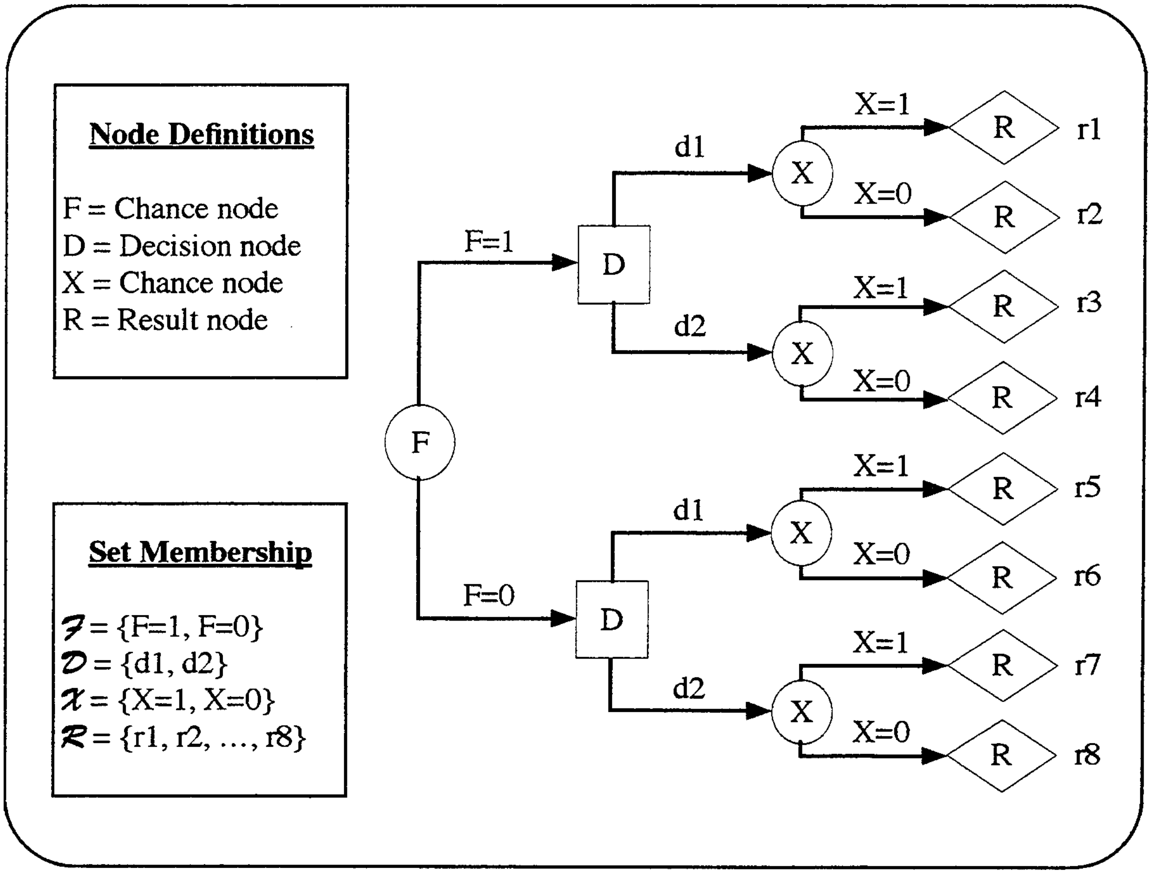

Figure 4. Example Decision Tree with Node and Arc Labels

{F=1, F=0}, the decision node D has a set of possible decisions $\mathcal{D}$ = {d1, d2}, the chance node X has a set of possible outcomes $\mathcal{X}$ = {X=1, X=0}, and finally the result node R has a set of possible outcomes $\mathcal{R}$ = {r1, r2, r3, r4, r4, r6, r7, r8}. The set $\mathcal{R}$ may contain eight distinct values or several outcomes may be the some value. The following steps are used to draw a discrete decision tree: (1) the decision tree is written out in chronological order

from left to right, with decision and chance nodes being connected by branches in the order they occur, (2) the branches stemming from each chance node are labeled with the possible outcomes (usually on top of the arc) and associated conditional probabilities (generally located on the bottom of the arc); the branches emanating from the decision nodes are labeled with the different decisions (usually located on top of the arc), and (3) the result nodes are labeled outcomes from the set $\mathcal{R}$, the alternatives. [Ref. 6:p. 125]

D. DECISION TREE EVALUATION

To evaluate a decision tree, a "simple procedure known as the 'rollback' algorithm which is based on the well-known principle of optimality" [Ref. 6:p. 127] is used. This algorithm's procedure starts from the result nodes and works backwards to solve the problem. The procedure begins at the value nodes (result nodes), and looks back (moves right to left) across the tree, and calculates the expected value at the random nodes and either maximizes or minimizes at decision nodes. This is continued "backward" until the entire tree is solved.

The following example illustrates this procedure. Using the decision tree in **Figure 4**, the event definitions listed below apply:

- D1 is the decision when F=1,
- D2 is the decision when F=0,
- X1 is the random event when F=1 and D=d1,
- X2 is the random event when F=1 and D=d2,
- X3 is the random event when F=0 and D=d1,
- X4 is the random event when F=0 and D=d2, and
- R is the set of all possible solutions.

The general form of the probability statements for the branches stemming from the chance nodes are

$p(i) = \Pr\{F = i\}$, where i = 0 or 1, and

$p(j \mid i, k) = \Pr\{X = j \mid F = i, D = k\}$, where i = 0 or 1, j = 0 or 1, and k = d1 or d2.

Enumerating these general equations yields the following statements:

- $p(1) = \Pr\{F = 1\}$,
- $p(0) = \Pr\{F = 0\} = 1 - p(1)$,
- $p(1 \mid 1,d1) = \Pr\{X = 1 \mid F = 1, D = d1\}$,
- $p(0 \mid 1,d1) = \Pr\{X = 0 \mid F = 1, D = d1\} = 1 - p(1 \mid 1, d1)$,
- $p(1 \mid 1,d2) = \Pr\{X = 1 \mid F = 1, D = d2\}$,
- $p(0 \mid 1,d2) = \Pr\{X = 0 \mid F = 1, D = d2\} = 1 - p(1 \mid 1, d2)$,
- $p(1 \mid 0,d1) = \Pr\{X = 1 \mid F = 0, D = d1\}$,
- $p(0 \mid 0,d1) = \Pr\{X = 0 \mid F = 0, D = d1\} = 1 - p(1 \mid 0, d1)$,
- $p(1 \mid 0,d2) = \Pr\{X = 1 \mid F = 0, D = d2\}$,
- $p(0 \mid 0,d2) = \Pr\{X = 0 \mid F = 0, D = d2\} = 1 - p(1 \mid 0, d2)$.

Figure 5 graphically shows these probabilities as applied to the decision tree.

Solving the tree for the general case, the rollback algorithm requires starting at the result nodes and work backwards, calculating expected values at the chance node and maximizing or minimizing at decision nodes. Since the first node encountered after a result node is a chance node, the expected values at each X chance node are as follows:

- $E[X1] = [r1 \times p(1 \mid 1, d1)] + [r2 \times (1 - p(1 \mid 1, d1))]$,
- $E[X2] = [r3 \times p(1 \mid 1, d2)] + [r4 \times (1 - p(1 \mid 1, d2))]$,
- $E[X3] = [r5 \times p(1 \mid 0, d1)] + [r6 \times (1 - p(1 \mid 0, d1))]$, and
- $E[X4] = [r7 \times p(1 \mid 0, d2)] + [r8 \times (1 - p(1 \mid 0, d2))]$.

Now with the expected values at each decision node calculated, the decisions D1 and D2 can be determined. If the problem is a maximizing problem, then

$D1 = \max\{ E[X1], E[X2] \}$, and

$D2 = \max\{ E[X3], E[X4] \}$

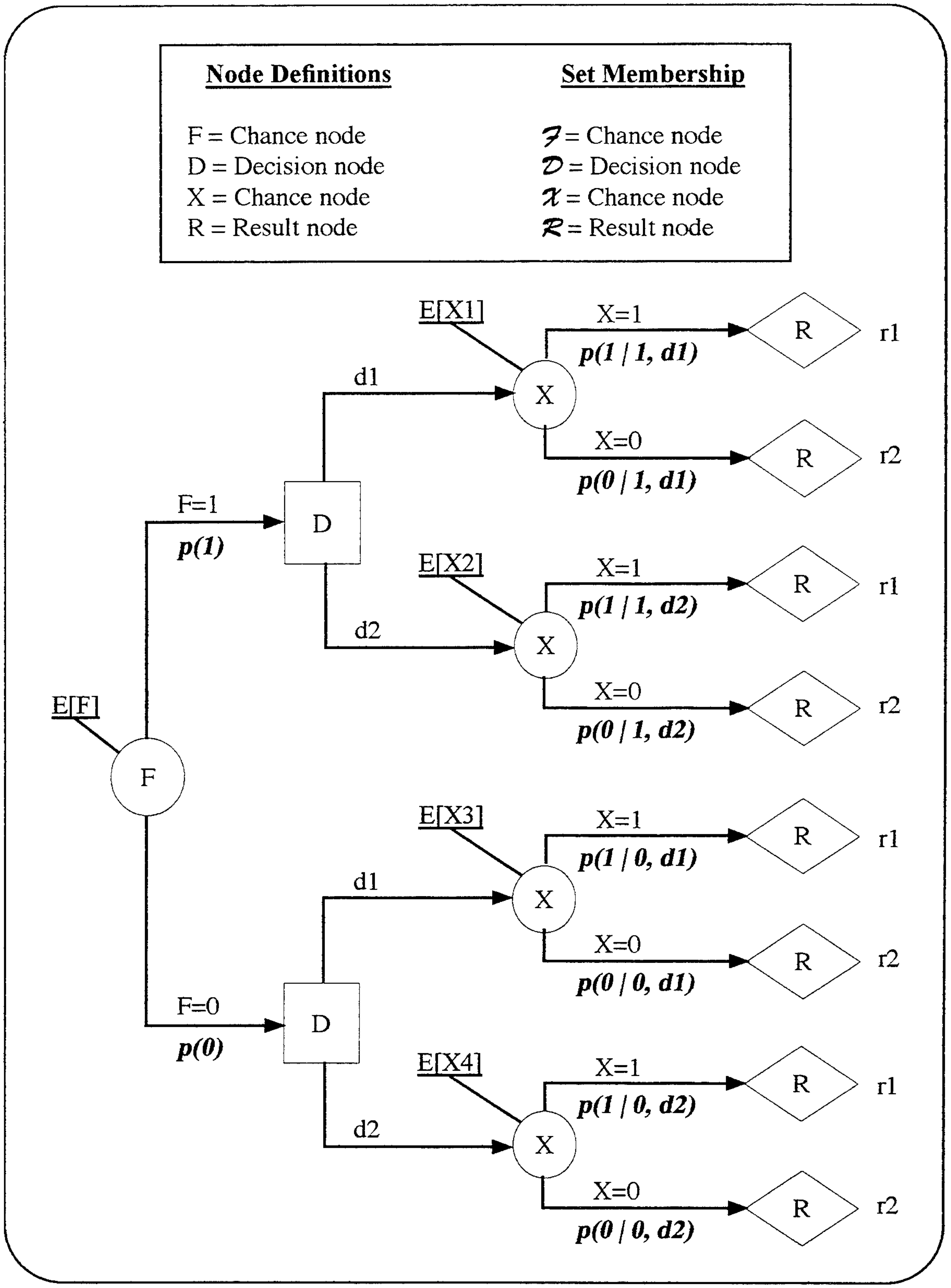

Figure 5. Decision Tree with Probability Statements

are the defining relations for the decisions. Calculating the expected value of the chance node, F, is straight forward:

$$E[F] = (p(1) \times D1) + (p(0) \times D2)$$

$$= (p(1) \times \max\{ E[X1], E[X2] \}) + (p(0) \times \max\{ E[X3], E[X4] \}) .$$

To interpret these results, the first step is to start at the chance node F, and look forward in time. The E[F] is the "value" of the random variable F, as shown in the equation above. If F = 1, the upper branch of the tree in **Figure 5**, then the optimal path, based on the previous calculations, is known. Obviously, if the probabilities at the chance node X are varied, the numbers will change, but the optimal path may or may not change. Varying the chance node X's probability such that a single $p(i \mid j, k)$ is varied while the remaining $p(i \mid j, k)$ values are fixed is called sensitivity analysis. Sensitivity analysis allows the calculation of the probabilities that produce "break-even" points (i.e., that point where E[X1] = E[X2]), and determines the optimal solution policy (the combination of solutions for the decision problem, where probabilities can vary over some range and still produce the same result) for the decision D. In this example, the optimal solution policy can be obtained for D1 and D2 by letting $p(i)$ be varied to yield a sensitivity of E[F][1].

With the basic ideas of influence diagrams and decision trees mentioned above, three areas of concern exist that must be addressed before the decision model can be used. First, the relationship between the different events and the order those events occur must be known. Second, the set $\mathcal{R} = \{r1, r2, r3, \ldots, r8\}$ must be determined for the particular

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1. "Decision Making and Forecasting", K.T. Marshall and R.M. Oliver [Ref. 6], provide extensive study in sensitivity analysis of decision problems.

problem at hand. It is not necessary that each "r" in the set $\mathcal{R}$ be different, only given the unique path to get to it, the value have "meaning" for the problem. Different problems have different measures of value for different outcome sets, $\mathcal{R}$ (e.g., outcome sets could consist of profit or loss; win, lose, or tie; buy or sell, etc., ...). Finally, the probabilities for the chance node must be known or estimated.

E. PERFECT INFORMATION

Perfect information is defined as the extreme or artificial situation where the outcomes of uncertain quantities are known before the decision is made. Although an artificial situation, the value of perfect information is that it provides the decision maker with the information necessary to judge whether or not to expend resources in actions that would help to better access or estimate uncertain future events (i.e., a forecast of a final outcome or a prediction of some future event) [Ref. 6:p. 22]. **Figure 6** shows a simple influence diagram and its corresponding perfect information influence diagram. Part (a) of **Figure 6** is the simple decision problem influence diagram, and part (b) is the perfect information influence diagram that corresponds to that decision problem.

If an expected value of the random variable X were computed in part (b) of the figure, the resulting value would be the value of perfect information for that decision problem. This value can be used in comparison with the expected values obtained from the random event X in part (a) of **Figure 6**. The difference between the value obtained in part

(b) and any of the values in part (a) would be the value of perfect information for that particular outcome.

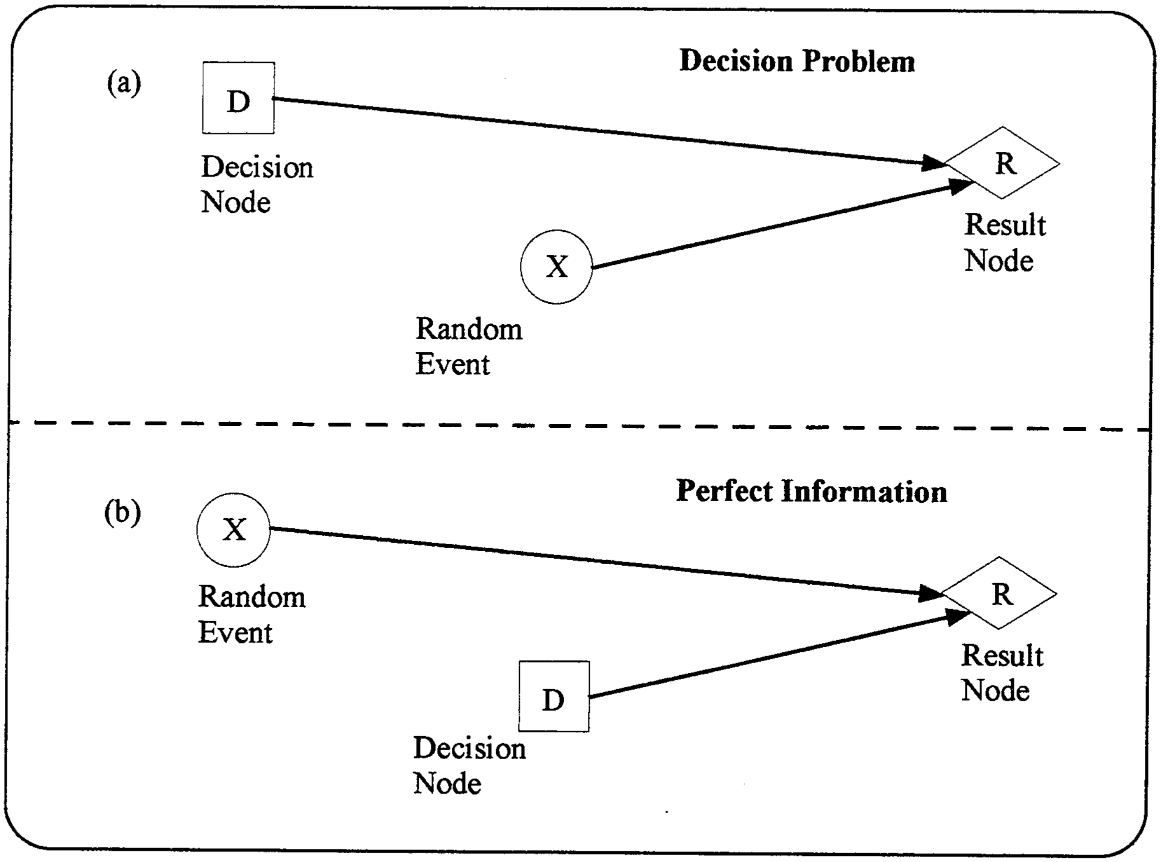

Figure 6. Perfect Information Influence Diagram

F. A GENERAL PARETO FRONTIER

As alluded to in the previous section, the random variable X in part (a) of **Figure 6** has an expected value for each decision D. For this simple example, no specifics to the decision problem are provided because only the concepts presented below are needed. For any decision, whether it be this example or a more complex problem, there exists some type of cost. This cost could be monetary value, some measure of value, or some

inherent property to the problem at hand, associated with making that decision. This thesis assumes a monetary cost for every decision made in the examples in this thesis. With this assumption, every decision in part (a) in **Figure 6** has a cost and an expected value or utility associated with it. A plot of those expected values (or utilities) versus its corresponding cost can be made. **Figure 7** shows a general plot of utilities versus cost.

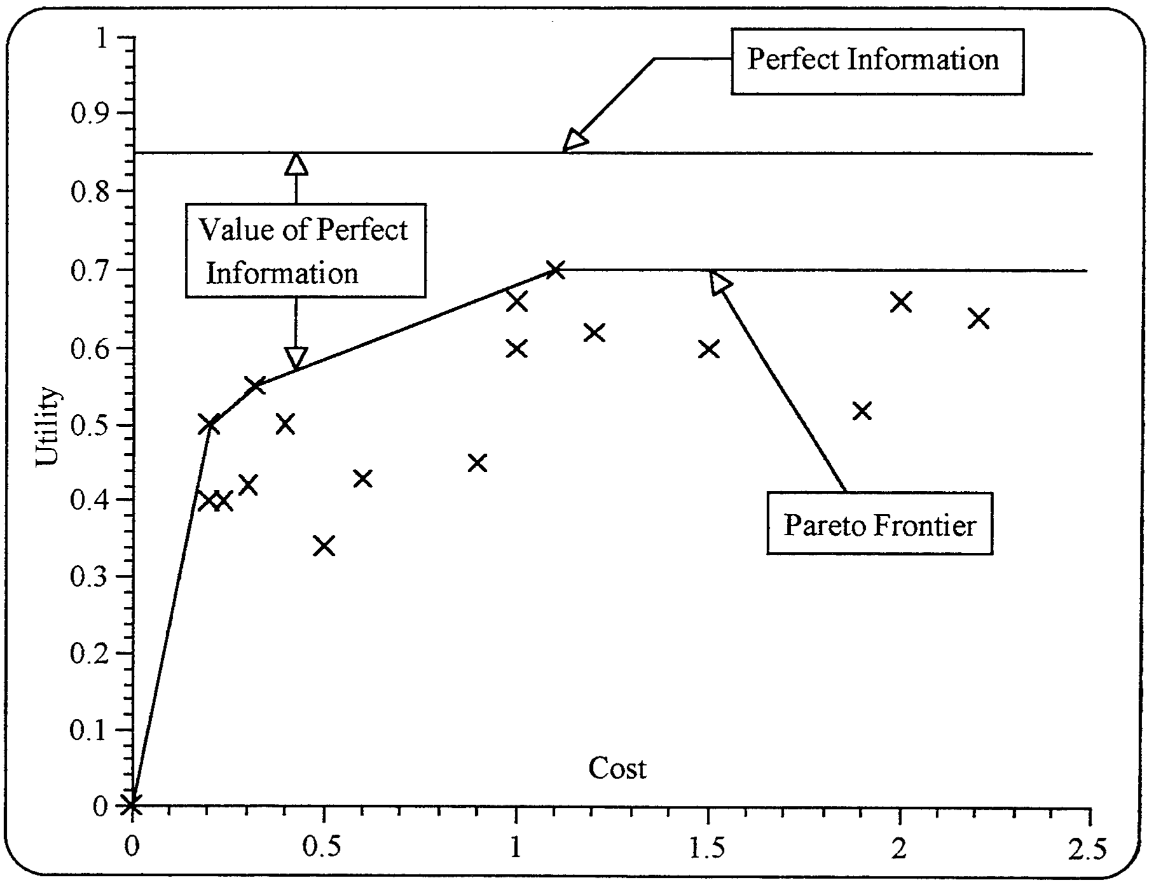

Figure 7. A General Pareto Frontier with Perfect Information

Again, the values used in the plot are not important, but the concepts presented below are. If a line where drawn connecting the highest values on the graph, ensuring the slope of each of the line segments were greater than or equal to zero, and ensuring that the completed curve was concave, then that curve would represent a Pareto frontier,

sometimes called an efficient frontier. **Figure 7** illustrates this idea. If the expected value obtained from perfect information were plotted as a horizontal line on the same graph, the difference would be the maximum expected gain in utility for a given cost. This difference allows the decision maker to judge whether or not to expend additional resources to increase the utility by trying to determine or estimate the outcome of the random event X in **Figure 6**.

G. SUMMARY

Using influence diagrams and decision trees as decision making tools allows the decision maker the ability to examine the dependencies and interrelationships among various decisions and random events and to compare the results of the different combinations of these decisions and random events. The influence diagrams allow the structure of the decision problem to be examined without formal mathematical or statistical notation and reduce large volumes of data into a portion of relevant and essential data necessary to the decision maker. Algorithms and numerical techniques can be applied directly to the influence diagrams to reduce their complexity. Decision trees provide a visual display of all the various combinations of sequences of decision events and random events that can occur in a decision problem.

The influence diagram allows the decision maker to understand and, if necessary, analyze the structure of the problem to gain insight to the problem. The decision tree allows the decision maker to investigate and observe the various results of all decision/ random event sequences of the decision problem. The decision tree produces an outcome

for each possible scenario of the decision problem. The decision tree is evaluated by what is known as the "rollback" algorithm. Essentially, each result is "worth" a certain value, each outcome of a random event has some type of probability, conditional or unconditional, associated with that outcome, and each decision of a decision event has an expected value associated with that decision. The "rollback" algorithm simply starts with each result and goes backwards across the decision tree, calculating expected values at each random event, and minimizing or maximizing at each decision event until all decision and random events have been evaluated.

Influence diagrams and decision trees can also be analyzed using the concept of perfect information and Pareto frontiers. Perfect information is an artificial situation where the outcomes of random events are known <u>before</u> the decision associated with that random event in made. It is useful in that it provides the decision maker with information necessary to judge whether or not additional resources should be expended in more accurately forecasting that random event. The Pareto frontier basically assumes some type of cost for each decision, and plots the cost versus the expected value for each decision. A concave curve is drawn through the highest points of the plot. This is the Pareto frontier. A line is drawn at the expected value of perfect information, and the difference between this line and the Pareto frontier is the value of perfect information.

Using these ideas and concepts this thesis develops a weapons configuration decision model for the SH-60B in the following chapter.

IV. BASIC CONFIGURATION DECISION MODEL

This chapter uses the tools developed in the previous chapter to solve, in detail, a sample problem. Because all SH-60B helicopter weapon configuration decisions are dependent on the situation at hand, a sample problem is chosen to capture the essence of a typical real decision problem. Since the decision process is the same for littoral and open ocean type scenarios, one model can be used to solve them both. As mentioned in **Section F** of **Chapter III**, all decisions incur some type of cost. Although this thesis was written for the operational level, and not the planning level, a monetary value for cost is used when decisions are made. At the operational level, it may be more appropriate to use some other type of resource to quantify other than dollar costs. In order to have a stable cost value for all operational situations, the recurring cost of weapons was used when available, or else the average unit cost was used. It should be understood that no decision is cost-free, whether it be money or some other quantifiable resource, and this cost aspect of the decision problem cannot be overlooked.

The decision that this thesis focuses on is "What should be the SH-60B helicopter's weapons configuration if the mission assigned is <u>not</u> known with certainty at the time the helicopter is configured?" This decision problem is then solved together with the perfect information problem associated with this decision (i.e., "What should be the helicopter's weapons configuration <u>given</u> an assigned mission?"). The former decision problem assumes that limited or no prior intelligence information of what the mission might be is

available at the time of the decision. **Chapter V** introduces the decision problem when intelligence information is available to the decision maker prior to making the decision.

A. MODEL DEFINITION

To limit the scope of the problem, a mission is defined as an assigned mission type, where the mission types are those defined in **Section A** of **Chapter II** and listed below: ASW (Anti-Submarine Warfare), ASST (Anti-Ship, Surveillance, and Targeting), RSTA (Reconnaissance, Surveillance and Target Acquisition), NSFS (Naval Service Fire Support), CSAR (Combat Search and Rescue), ECM (Electronic Counter Measures), MCM (Mine Counter Measures), Boarding, and "Other." The mission definition assumes that the threat particular to a mission is present in the battlespace (e.g., the sea, air and land environment where operations are conducted). **Table 4** lists the primary threat for a given mission and lists weapons required for a given mission. The first column of **Table 4** lists the nine mission types that may be assigned to a SH-60B. The second column identifies a "primary" threat associated with its respective mission. It is noted that these are just examples of threats for a given mission and not the only threats. The third column represents the weapons required for a given mission. It should be understood that this is an example and these weapons are used in that context. A further limitation of the mission definition is that only those missions where weapons are required, or assist in, the completion of the mission in a littoral warfare scenario are considered for this model. By the above definitions, only the following missions will be included in the model: ASW, RSTA, NSFS, CSAR, MCM, and Boarding. The outcome set, $\mathcal{R}$, associated with this

problem is either mission successful or mission unsuccessful. A successful mission is defined as completing the assigned mission where at least one of the following situations occurred, (1) a threat was neutralized with weapons before threat weapon engagement occurred, (2) threat engagement was deterred, or (3) no threat contact was made. An unsuccessful mission is defined as any situation other than above.

TABLE 4. MISSION-THREAT-WEAPON REQUIREMENTS

Mission	Threat	Weapons Required
ASW	submarine	torpedo, bombs
ASST	surface vessel	none required
RSTA	surface vessel	Hellfire, rockets, forward firing gun, Penguin
NSFS	fixed target	Hellfire, rockets, forward firing gun
CSAR	widely varying	Hellfire, rockets, forward firing gun
ECM	missiles	none
MCM	mines	bombs, forward firing gun
Boarding	personnel	forward firing gun, rockets, Hellfire
"Other"	none	none

B. HELICOPTER CONFIGURATION UTILITIES

In order to model this problem properly, the value or utility of each configuration applicable to a given a mission must be determined. This can be accomplished in a variety of ways. One approach is to use a technique called the Analytic Hierarchy Process (AHP) [Ref. 9]; another approach is using indifference probabilities. This thesis uses indifference probabilities to find the utility of each applicable configuration for each mission.

Indifference probabilities are discussed below. An applicable configuration is one that contains any or all required weapons necessary to perform the assigned mission (see **Table 4**). Using combinations of these weapons for each mission yields a list of applicable weapons configurations for a given mission. **Appendix B** lists these applicable weapons configuration combinations for each of the six mission types included in the decision problem.

Before defining indifference probabilities, a decision sapling must first be introduced. **Figure 8** shows a decision sapling with payoff values for both the general case, denoted as r_i, with i = 1, 2, 3, and the "utility" case as used in this thesis, where the utility of a particular configuration is some measure of value as defined by indifference probabilities (discussed below). For the general case, the decision to take a "riskless venture," would require the utility r_2 to be at least equal to the expected value of the "risky venture." The expected value of the "risky venture" is defined algebraically as: E["risk"] = $\{ (p \times r_1) + ((1 - p) \times r_3) \}$, where E[ ] is the symbol for the expected value of the random variable inside the brackets and "risk" is an abbreviation for "risky venture." If r_2 were less than the E["risk"], then the decision would be to choose the "risky venture." The indifference probability is defined as the value of p that satisfies the equation: $r_2 = \{ (p \times r_1) + (1 - p) \times r_3) \}$. In other words, indifference probabilities are those probability values, p, where the utility of the "riskless alternative" is equal to the expected utility of the "risky venture." The decision sapling in **Figure 8** is a graphical representation of the decision between a "riskless alternative" and a "risky venture" (e.g., a choice to obtain a fixed reward for certain, the "riskless alternative", or take a gamble with a probability of

obtaining something better than the "riskless alternative" or something worse, the "risky venture." [Ref. 6:pp. 42,45]

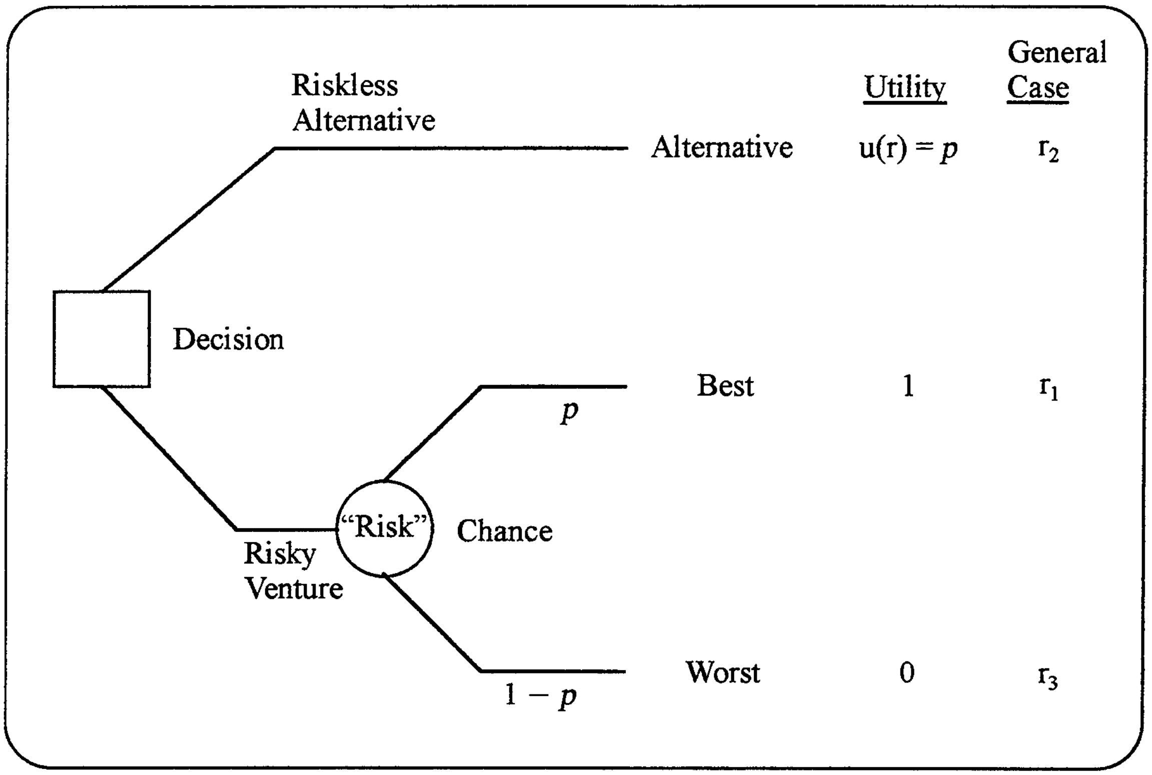

Figure 8. General Decision Sapling

Leaving the general case, for a given problem the "best" choice of the available choices is assigned a utility of 1, and the "worst" choice is assigned a utility of 0 (for this thesis the "BASE" will always be the "worst" choice), and the "riskless alternative" utility is defined as u(r), as shown in **Figure 8**. This yields an

E["risk"] = $\{ (1 \times p) + (0 \times (1 - p)) \}$ = p, or

E["risk"] = p.

To find the utility of the alternatives that exist between the "best" and "worst" alternatives,

substitute them as the riskless alternatives. The utility of the "riskless alternative" is found by equating expected values between the two decision choices, the "riskless alternative" and the risk. This "break-even" point is shown as

$$E[\text{"riskless alternative"}] = u(r) \times 1 = p = E[\text{"risk"}]$$

$$= p.$$

This is the utility of that particular "riskless alternative" and, by the general case above, the indifference probability for that "riskless alternative." This procedure is done for each alternative that exists between the "best" and "worst" alternatives. [Ref. 6:pp. 421 - 427]

To use the indifference probabilities as utilities, the following six Axioms of Utilities must be adhered to:

- the existence of a preference ordering,
- transitivity of preference ordering,
- continuity among elements,
- reduction of mixtures,
- substitutability, and
- monotonicity.

Preference ordering is the ability to compare every two elements in a set and rank their ordering. Transitivity of preference ordering states that: given r_1 is preferred to r_2, and r_2 is preferred to r_3, then r_1 must be preferred to r_3. Continuity among elements is the ability to find an indifference between choosing a risk or a guaranteed result. Reduction of mixtures states that if a result, r_i, can be obtained by two different probability sets, p_i and q_i, and the probability of choosing from the set p_i is $\boldsymbol{s}$ and the probability of choosing from set q_i is (1-$\boldsymbol{s}$), where $r_i = (\boldsymbol{s} \times p_i) + ((1 - \boldsymbol{s}) \times q_i)$, then there is indifference in choosing from either probability set p_i or q_i. Substitutability states that if the decision maker is willing to

take the risk over a guaranteed result, then he is willing to take the risk in every aspect of the problem. Monotonicity is always preferring the risk with the largest probability of obtaining the best result. [Ref. 6;pp. 421 - 424]

The following example illustrates the idea of indifference probabilities. The mission assigned is ASW. From **Table 4**, the weapons required are torpedoes and bombs. **Figure 9** shows the decision sapling and the indifference probability determined by the author. For

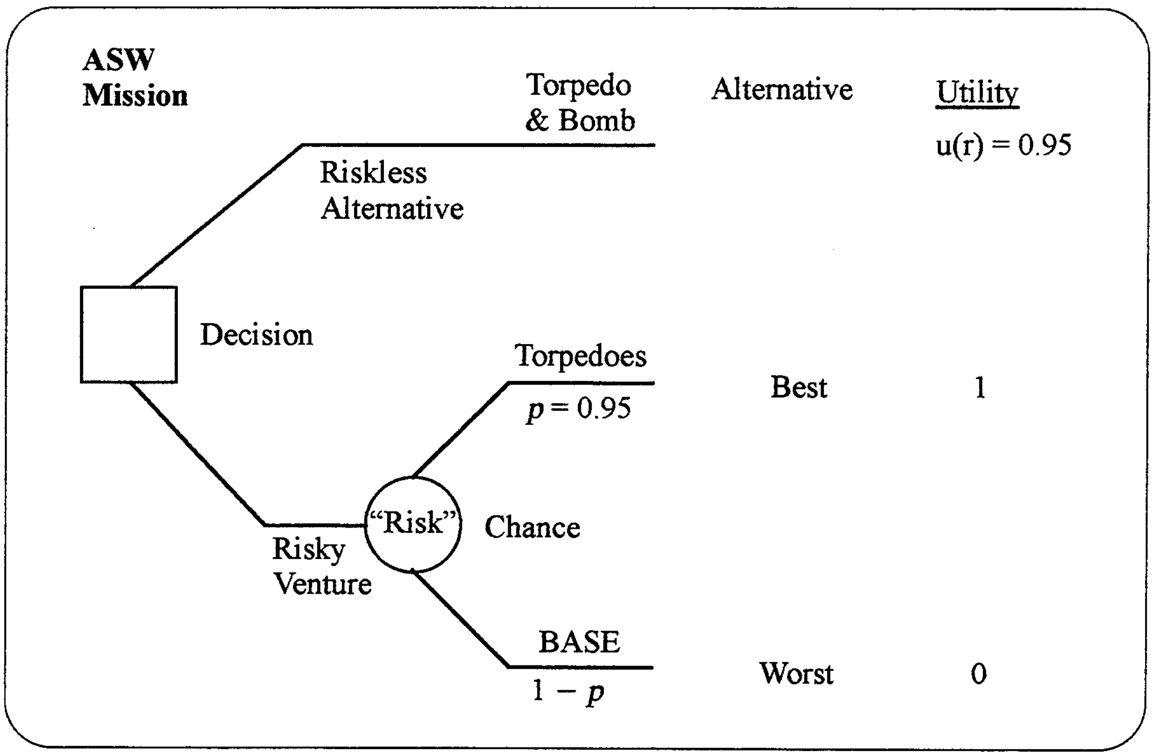

Figure 9. Decision Sapling for ASW Mission

this case, the author considers a torpedo and a bomb much better than the "BASE" configuration, which has neither. Therefore, he assigns a value of $p = 0.95$ to the "risky venture." This means if a torpedo and a bomb were on the aircraft, and an ordnanceman told the aircrew they could keep the torpedo and bomb or they could take a chance of

getting two torpedoes or no weapons at all, the aircrew must have a 95% chance of getting the two torpedoes in order to take the "risky venture." The utility of the torpedo and the bomb is, therefore, u(r) = 0.95 on scale where two torpedoes is 1.0 and no weapons is 0.

When more than three combinations of weapons are available for a mission, consistency checks should be performed to ensure the assumptions for using indifference probabilities as utilities are not violated. To perform consistency checks, one must complete the indifference probability procedure for all alternatives. Next, change the "worst" option in the "risky venture" to another alternative and repeat the indifference probability procedure with the other alternatives. Then substituting the utilities calculated in the first indifference probability procedure for the risks, calculate the expected values of the "riskless alternative." That E["risk"] should be very close to the u(r) assigned in the second indifference probability procedure. Repeat this procedure for all combinations to ensure consistency. It should be noted that this procedure is very time consuming. Other procedures for checking consistency are outlined in Reference 6.

All the remaining indifference probabilities for the configurations for each mission were generated as in the example above. **Appendix C** displays the decision sapling for the indifference probabilities for each mission used in the model and relevant weapon combination associated with that mission. **Table 5** lists the summary results of this procedure. For each mission type (i.e., ASW, RSTA, NSFS, CSAR, MCM, and Boarding) used in the model, the utility of a weapons package that includes weapons not useful on a given mission (i.e., the weapon is not tactically significant with respect to the mission and does not occupy a weapon station that can be used by a "useful" weapon) is the same as it

TABLE 5. SH-60B WEAPON CONFIGURATION UTILITIES

Mission	Weapon Configuration	Utility using Indifference Probabilities
ASW	T...........................	1.0
	B...........................	0.50
	T + B..................	0.95
	BASE....................	0
RSTA	HF........................	1.0
	R..........................	0.80
	P..........................	0.75
	FF........................	0.50
	HF + R................	0.98
	HF + P................	0.95
	HF + FF..............	0.92
	R + P.................	0.88
	R + FF...............	0.85
	P + FF................	0.78
	BASE...................	0
NSFS	HF........................	1.0
	R..........................	0.75
	FF........................	0.65
	HF + R................	0.95
	HF + P................	0.70
	HF + FF..............	0.90
	R + P.................	0.68
	R + FF................	0.85
	P + FF................	0.65
	BASE...................	0

TABLE 5. SH-60B WEAPON CONFIGURATION UTILITIES

Mission	Weapon Configuration	Utility using Indifference Probabilities
CSAR	HF......................	0.75
	R.........................	0.70
	FF.......................	0.60
	HF + R................	1.0
	HF + P................	0.72
	HF + FF..............	0.85
	R + P.................	0.65
	R + FF................	0.75
	P + FF................	0.60
	BASE...................	0
MCM	B........................	0.98
	FF.......................	0.50
	B + FF...............	1.0
	T + B.................	0.90
	T + B + FF........	0.95
	BASE..................	0
Boarding	HF......................	0.50
	R.......................	1.0
	FF......................	0.70
	HF + R..............	0.80
	HF + P..............	0.75
	HF + FF............	0.30
	R + P................	0.95
	R + FF..............	0.90
	P + FF..............	0.70
	BASE.................	0

would be if these weapons were not included in the weapons package. For example, in an ASW mission, a "torpedo + Hellfire missile" weapons package is no more and no less effective than a "torpedo" weapons package (e.g., there is no tactical advantage to carrying Hellfire missiles on a ASW mission and the Hellfire missiles are only loaded on the primary weapons stations and the torpedo is loaded only on the secondary weapon stations {see **Figure 1** on page 12 and **Section C** of **Chapter II** on page 14}). However, the costs associated with these two configurations or weapon packages are different. All other configurations and all outcomes which end in mission failure have a utility value of zero. It should be understood that these are the author's judgments and used only for the purposes of this thesis. Since the decision model is for illustrative purposes no formal consistency checks were made, however, logic checks were used to minimize the errors in consistency.

C. REQUIRED DATA

Before the decision model can be constructed, the set membership for each type of node (see **Section A** of **Chapter III** on page 19) must be well defined. The set definitions are listed below:

- $\mathcal{C}$, helicopter configuration = {**Table 3**},
- $\mathcal{M}^*$, mission assigned = {ASW, RSTA, NSFS, CSAR, MCM, Boarding},
- $\mathcal{X}$, mission outcome = {mission successful (1), mission unsuccessful (0)},
- $\mathcal{R}$, configuration utility = {**Table 5**}.

Using the information and data obtained above, the entire decision tree would consist of **44** configurations $\times$ **9** mission types $\times$ **2** outcomes = **792** alternative choices. Since there were only six missions with weapons, the alternative choices drops to 528

alternatives. However, being cognizant of the limitations imposed on the model (see **Appendix B** for the model's configuration-mission assignments), the number of alternatives for this decision tree are

211 configuration-mission assignments $\times$ **2** outcomes = **422** alternative choices.

To be able to complete the decision tree, three additional pieces of information, listed below, must be obtained,

- c(j) : the cost of configuring a helicopter with the jth configuration, $j \in \mathcal{C}$,
- *p(i)* : the Pr{mission = i}, $i \in \mathcal{M}^*$,
- *p(s | i, j)* : the probability of mission success given mission i and helicopter configuration j, (e.g., Pr{X = 1 | mission = i, configuration = j}), for $s \in \mathcal{X}$, $i \in \mathcal{M}^*$ and $j \in \mathcal{C}$.

For the purposes of illustration, the values for these parameters are assigned as discussed below. The c(j) values used were obtained from the 1993 Military Cost Handbook [Ref.10] and a Pentagon briefing on armed helicopters for ASUW [Ref.11]. The cost values for the Penguin missiles, torpedoes, and bombs are the "average cost", as defined in Reference 10. The cost values for the 2.75 inch rockets, a forward firing gun, and the Hellfire missiles are recurring kit costs as explained in Reference 11. The c(j) value for the "BASE" configuration is assigned the value of zero since no weapons are loaded in this configuration. **Table 6** lists the c(j) values used for this thesis. Since some configurations required more than one kit or weapon, those c(j) values listed in **Table 6** are multiplied by the appropriate number of kits or weapons loaded onto the helicopter. The c(j) values are additive for configurations with different weapons loaded. **Table D1** of **Appendix D** lists the costs associated with each configuration. The *p(i)* values were obtained by using a uniform random number generator bounded between 0.5 and 9.5. The bounds on the

TABLE 6. WEAPON CONFIGURATION COST

Weapon	Cost, c(j) (millions $)	Quantity per Cost
Penguin missile	1.057	1
Hellfire missiles	0.015	4
2.75 inch rockets	0.01	19
Forward firing gun	0.05	1
Mk-50 torpedo	1.137	1
500 lb. bomb	0.002	1

random number generator are assigned only to prevent a zero probability of a mission occurring. Other than this constraint, the bounds were subjectively assigned by the author. The *p(i)* values were initially obtained for all nine mission types identified in **Chapter II**, by using the random number generator. Since only six of the mission types utilize weapons (see **Table 4** on page 35), these six mission types are the only missions necessary in the decision model (e.g., since the ASST does not require any weapons to perform its mission, so for the purposes of this thesis, that mission type is independent of any weapon configuration). Since these three missions might be assigned, a probability value must be assigned to them. However, only the six missions with weapons are of concern, so those six probabilities are normalized to one. Otherwise, the results, with respect to utility, would be smaller than they actually are. The *p(s | i, j)* values were subjectively assigned by the author to indicate a reasonable probability of mission success for each mission-configuration combination. **Table D2** and **D3** of **Appendix D** provides a spreadsheet view of the complete decision model. **Table D2** is for the missions with weapons and **Table D3** is for the missions without weapons. This table groups the 44 feasible configurations (see

Table 3 on page 15) by mission, lists a cost for each configuration, and lists the utility for each mission-configuration combination (if a configuration is not feasible for a mission, a utility value of zero is assigned to ensure that the mission-configuration combination is not considered in the decision model). It also lists the $p(i)$ values for each mission and lists the $p(s \mid i, j)$ values for each mission-configuration combination. For each mission-configuration there is a $p(s \mid i, j)$ value a $(1 - p(s \mid i, j))$ value, therefore **Table D2** as two rows for each mission-configuration, one for each value. The second rows, having no mission or configuration labels, are the $(1 - p(s \mid i, j))$ values. The second row is academic, because this row relates to mission failure, which has a utility of zero. Therefore this row provides no useful input to the model, but has been included for completeness. The remaining columns in **Table D2** are simple calculations used in computing the configuration utility.

Now that all the necessary information is available, the influence diagram and the decision tree can be constructed and a solution set obtained. **Section D** of this chapter details the influence diagram and the decision tree and interprets the results.

D. INFLUENCE DIAGRAM AND DECISION TREE

The influence diagram and the decision tree must follow the time ordered sequence of events. For this example, the following chronological operational events occur: (1) the helicopter is configured to fly, (2) a mission is assigned through a tasking order, (3) a mission outcome is realized (this assumes the mission assigned is flown by the helicopter), and (4) the result or utility of the mission is achieved. Using this information, the influence

diagram can be constructed as shown in **Figure 10.** The ordering of the different nodes reflects the problem definition stated earlier. The configuration decision is shown as the square node, the two random events (mission assignment and mission outcomes) are shown as the circular chance nodes, and the results of the outcomes are shown in the triangular node. The directed arc from the configuration decision node to the mission

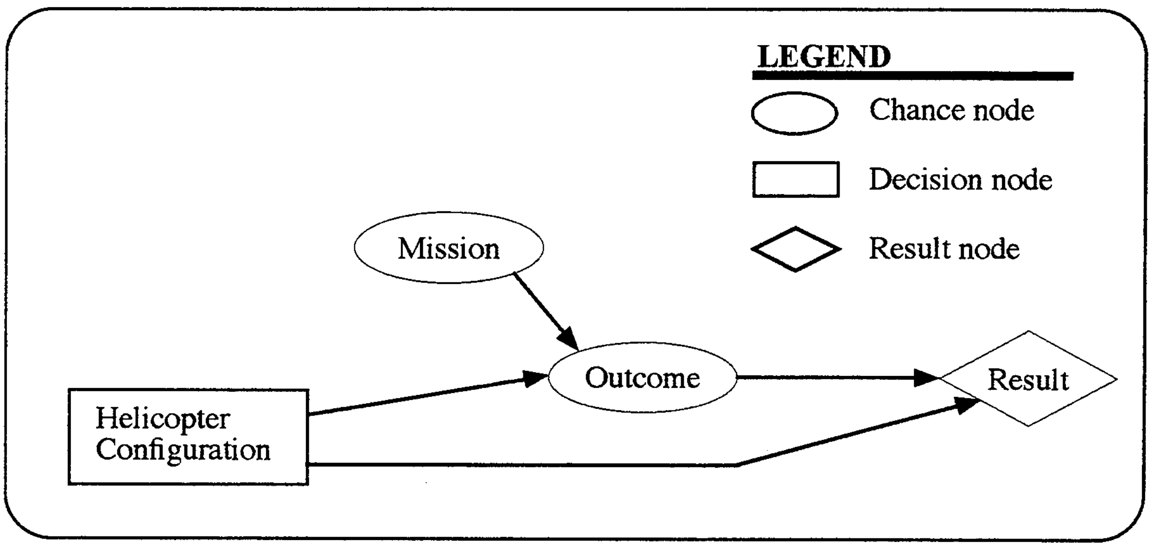

Figure 10. Influence diagram for SH-60B Weapon's Configuration

outcome chance node reflects the conditional dependence of the mission outcome on the aircraft configuration. It also shows the decision to configure the SH-60B happens before the probability distribution of the outcome of the mission is determined. The directed arc from the mission assignment chance node to the mission outcome chance node reflects (1) the conditional dependence of the outcome of the random event of mission assignment to the random event of mission outcome, and (2) the result of the mission assignment is known before the probability distribution of the outcome of the mission is determined.

The directed arc between the mission outcome chance node and the result node indicates that the mission outcome is known before the result of the problem is achieved.

With the influence diagram constructed and the dependencies and relationships understood, the decision tree can be created. Ensuring the event order is maintained, as in the influence diagram, the decision tree is drawn. Since the complete decision tree for this model would contain 528 end nodes and all branches stemming from each configuration decision node are the same, a single branch from a configuration node is shown in **Figure 11**. The branches that stem from the mission chance node are the six missions from **Table 4** that have weapons requirements. The branches that emanate from the outcome chance nodes are either a mission successful (X=1) or a mission failure (X=0). The branches that emanate from the mission chance node are labeled with the appropriate missions on the top of the branch and the probability of a particular mission occurring below the branch. The outcome chance nodes all consist of either mission success or mission failure labels. The joint probability of achieving a mission success for a specific mission is also shown in **Figure 11**. The probability of the mission failure branch is one minus the probability of the mission success branch. The utility is shown for each possible outcome for a given configuration. The branches stemming from the configuration chance node are labeled C_j (where $j \in \mathscr{C}$, see **Section C** of **Chapter IV** on page 43) and are the 44 feasible configurations listed in **Table 3** on page 15. **Appendix B** lists the configurations that provide some utility for a given mission, and **Appendix D** lists all the information contained in the entire decision tree in tabular form. The decision tree in **Figure 11**, if shown in full, would show all configuration-mission combinations. Those configuration-

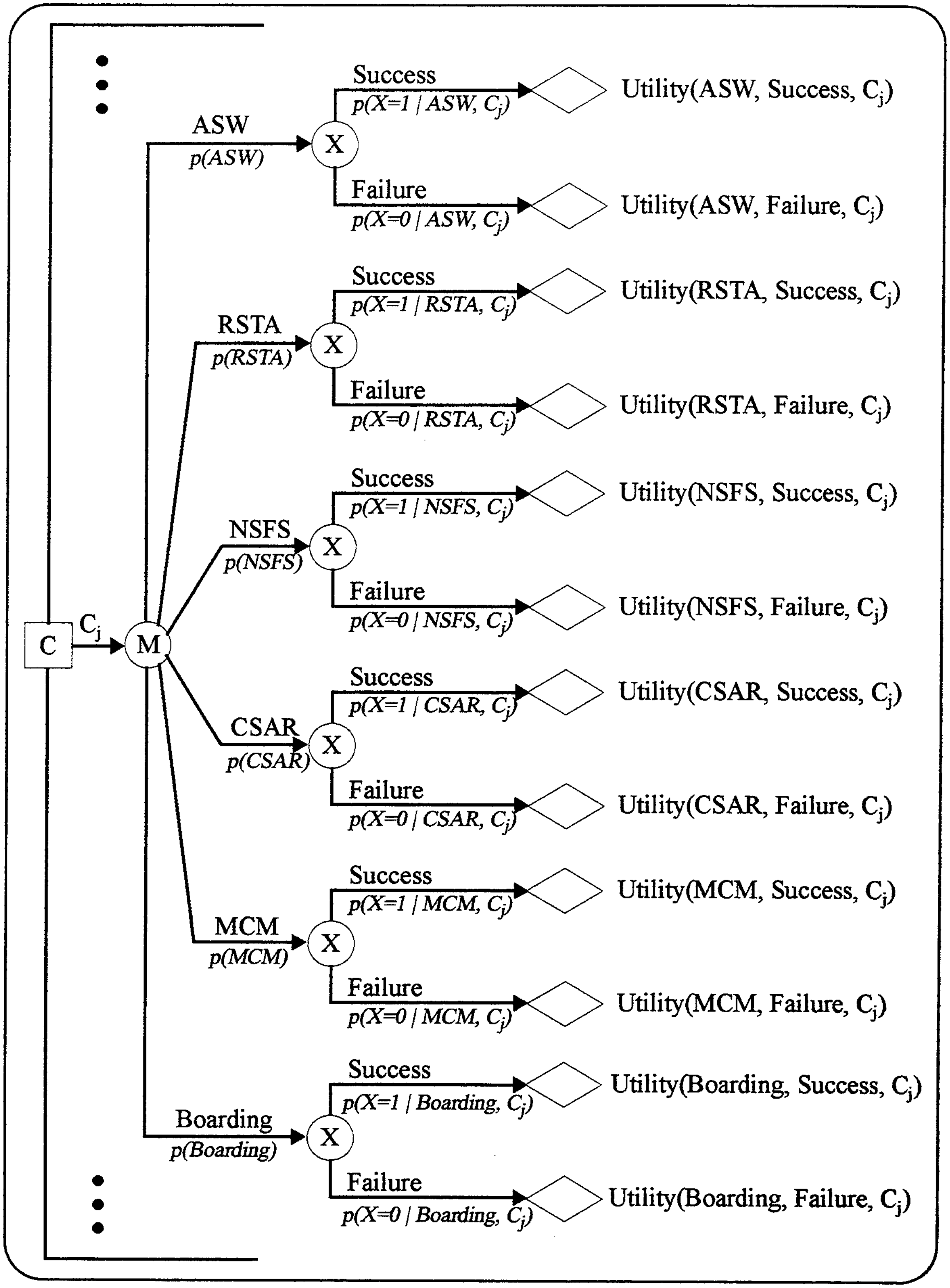

Figure 11. Single Branch for the General Configuration Decision Problem

missions with zero utility may be left out for brevity, without changing the nature of problem.

The values that reside on the branches of the decision tree that are created by the directed arcs between the "outcome" chance nodes and the result nodes are the $p(s \mid i, j)$ probabilities (defined in **Section C** on page 43 and listed in **Table D2** of **Appendix D**). The values that reside on the branches between the mission assignment nodes and the outcome nodes are the $p(i)$ probabilities (defined in **Section C** on page 43 and listed in **Table D4** of **Appendix D**). The values assigned to the branches that stem from the decision node to the mission assignment node are called the cost of the configuration, $c(j)$ (defined in **Section C** on page 43 and listed in **Table D1** of **Appendix D**). **Figure 12** shows the Hellfire configuration decision tree with the appropriate values as taken from **Appendix D**. These values are also listed for each configuration branch in **Appendix D** in tabular form. **Figure 12** also shows the expected values for each random event in the branch of the tree. For this example, the Hellfire configuration has an expected value of utility of 0.417. The use of this value is discussed below.

As explained in **Section D** of **Chapter III**, the expected values were calculated for the chance nodes and the optimum configuration decision is determined by the maximum of the 44 expected values of mission utilities. The result gives the maximum mission utility for each configuration. From this information, the configuration with the highest utility can be determined. Perfect information (see **Section E** of **Chapter III**) for this problem is now calculated to determine the maximum mission utility over all the configurations. Knowing this information would determine the "value" of forecasting

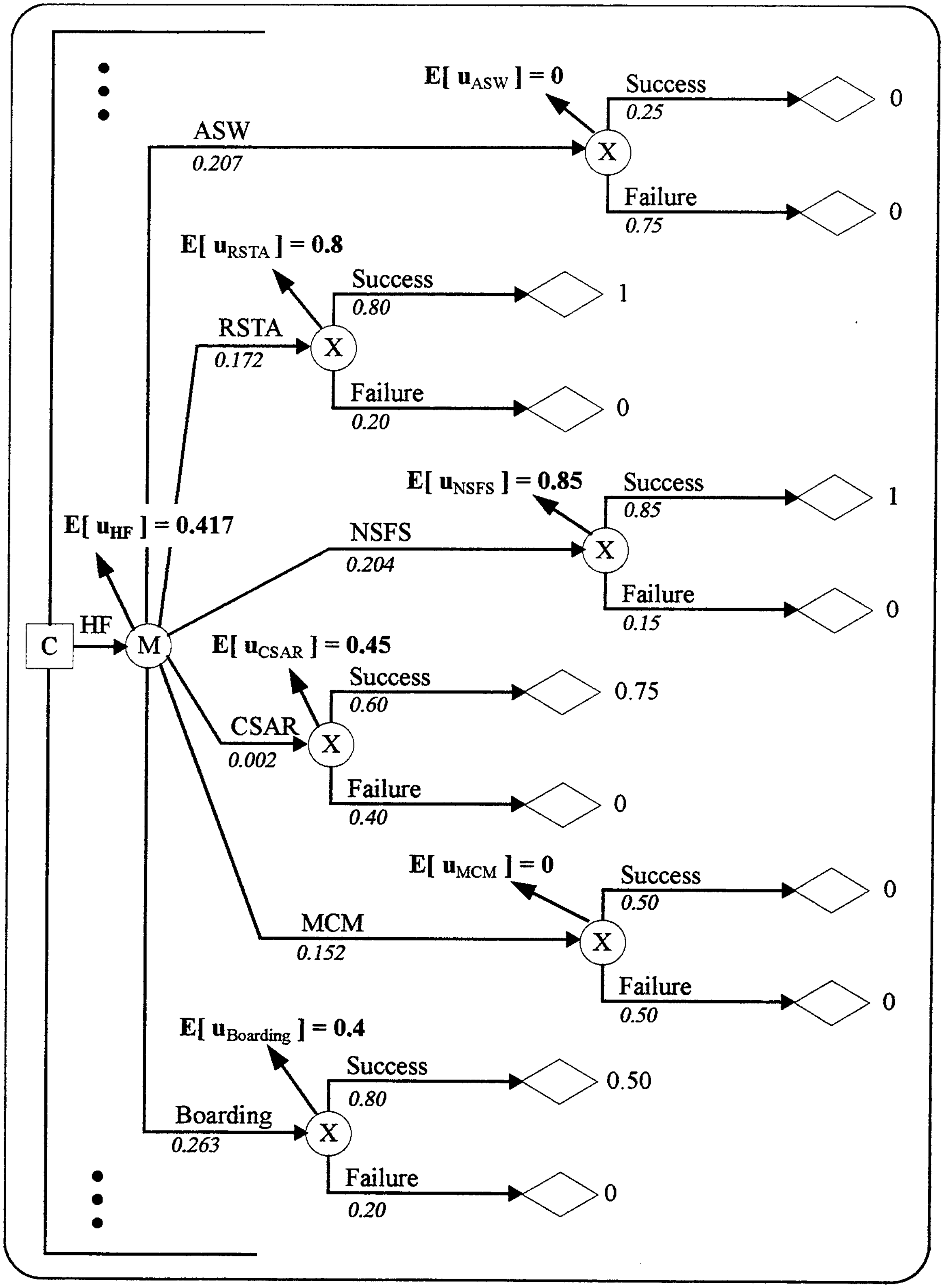

Figure 12. Hellfire Configuration Decision Tree Branch with Example Values

(gaining intelligence information) or usefulness of predicting what the mission would be before the helicopter was configured. **Figure 13** shows the influence diagram for perfect information on the mission type for the configuration decision problem. The arc from the mission chance node to the configuration decision node indicates the outcome of the random event of mission assignment is known before the configuration decision is made, and that outcome may have some influence on the configuration decision. The directed arc

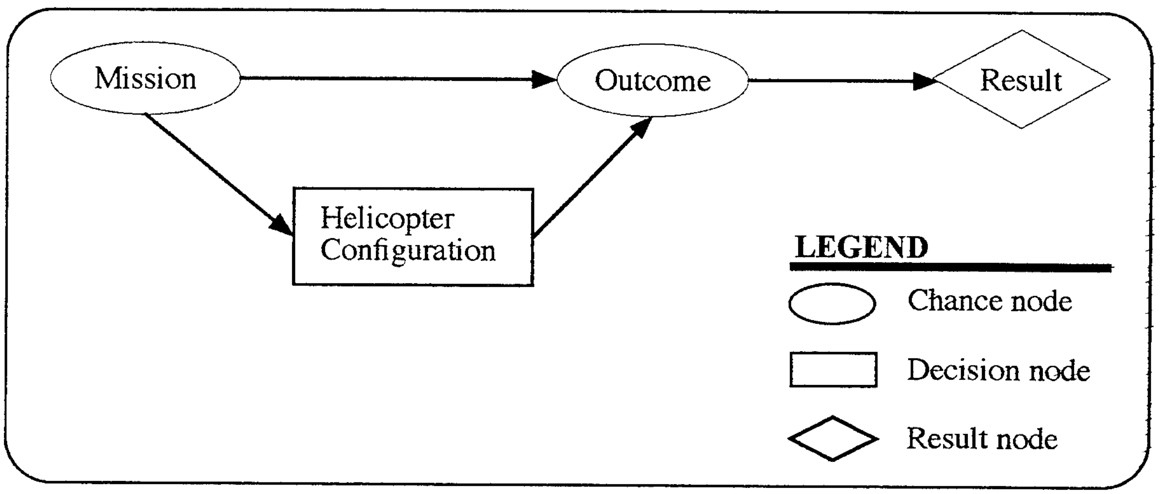

Figure 13. Perfect Information Influence Diagram

from the mission chance node to the outcome chance node indicates the random event of mission assignment is known before the outcome is realized and the mission outcome may influence the success or failure of the mission. The directed arc between the configuration decision node and the outcome chance node indicates the configuration of the helicopter is known before the outcome is known and may have some influence on what the outcome will be. The result is the set of possible solutions to the problem. **Figure 14** shows the

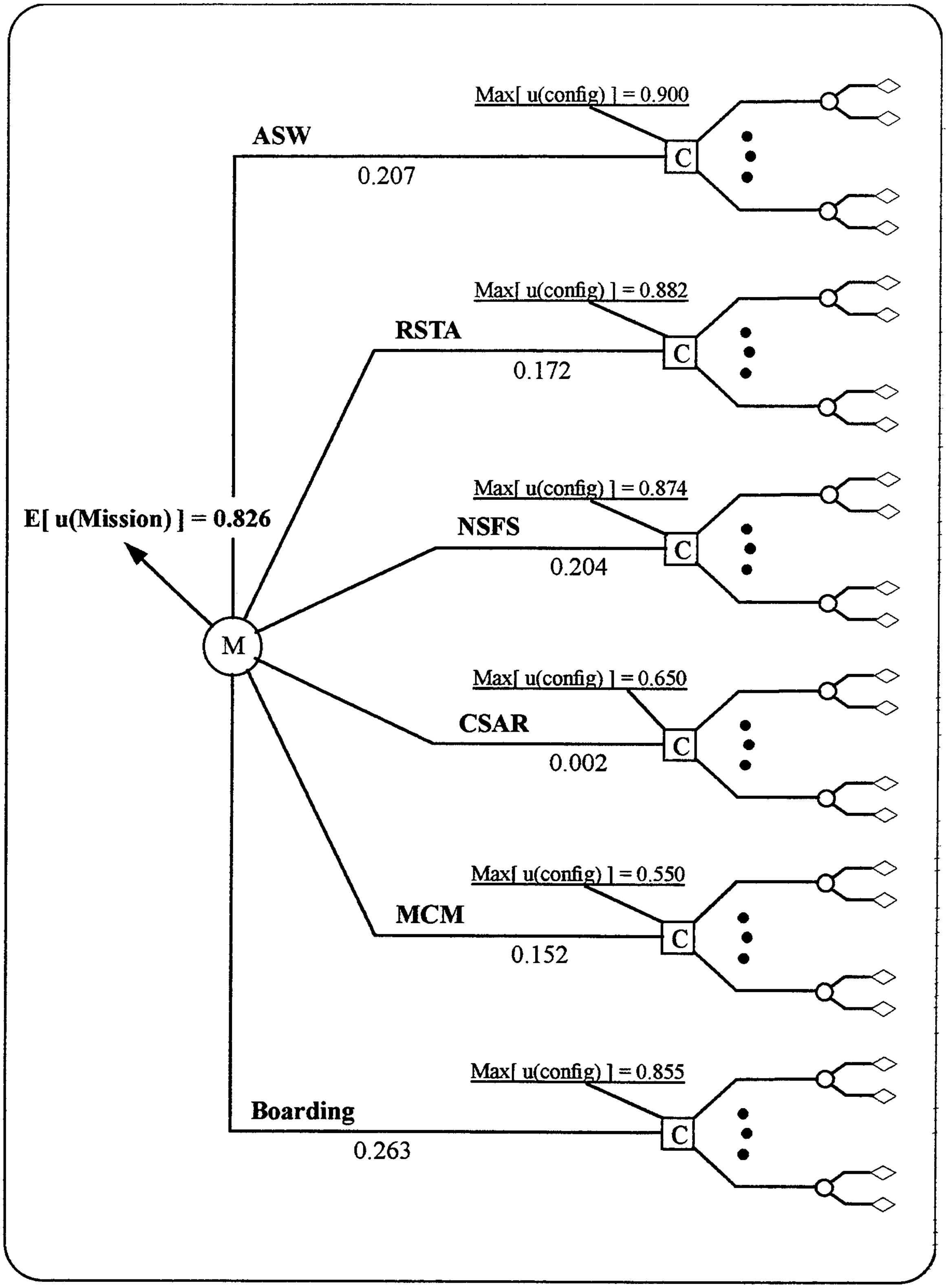

Figure 14. Perfect Information Decision Tree

decision tree for perfect information that is associated with the influence diagram in **Figure 13**. The values are taken from the calculations in **Appendix D**.

The symbol ***max[u(config)]***, in **Figure 14**, means the maximum value of the utilities over all the configurations for each particular mission. **Table 7** lists the configuration associated with this value. If perfect information were available, then these

TABLE 7. WEAPONS CONFIGURATIONS FOR PERFECT INFORMATION

Mission	Maximum Expected Mission Utility	Weapons Configuration
ASW	0.900	all configurations with 2 torpedoes
ASST	0	any configuration
RSTA	0.882	all configurations with Hellfire and rockets
NSFS	0.874	all configurations with Hellfire and rockets
CSAR	0.650	all configurations with Hellfire and rockets
ECM	0	any configuration
MCM	0.550	all configurations with a forwarding firing gun and bombs
Boarding	0.855	all configurations with a forwarding firing gun and rockets
Other	0	any configuration

configurations would be the helicopter's weapon configuration for each mission in order to achieve a maximum mission utility. The probability of each mission is listed under the appropriate branch label. The decision tree has ellipses in the configuration branches to indicate the 44 configurations that are possible for each of the six missions identified in the

problem statement. The configuration branches, the outcome branches, and result nodes are not labeled to minimize clutter on the figure. The expected value of the mission chance node, E[u(Mission)], is the expected value over all the missions. The E[u(Mission)] is computed by multiplying the probability of each branch with its respective maximum utility, then adding these six products to produce the expected value, the expected value of the utility of perfect information.

With the information from the original problem and the perfect information solution available, the decision maker has the necessary information to evaluate and choose a particular solution to the problem at hand. To display the information to the decision maker in a concise and convenient manner, a Pareto frontier plot is constructed. **Figure 15** is the Pareto frontier for this problem. The Pareto frontier, for this problem, is a plot of the configuration utilities (i.e., the expected value of u_j, $j \in \mathscr{C}$, in **Figure 12** on page 51) versus the configuration cost (see **Section C** on page 44) for each of the 44 configurations. **Table D5 of Appendix D** lists these values in tabular form.

From the Pareto frontier for this example, four cost ranges can be seen. The first cost range is between \$0 and \$100,000; the second cost range is between \$1.0 million and \$1.2 million; the third cost range is between \$2.1 million and \$2.4 million; and the fourth cost range is between \$3.2 million and \$3.4 million. The Pareto frontier is the concave curve that bounds the highest configuration utility as the configuration cost increases from its lowest to highest value, shown as a bold line in **Figure 15**. The utility of perfect information on mission type is the expected value of the missions, as shown in **Figure 14**. This value is indicated on **Figure 15** by the horizontal line at configuration utility equal to

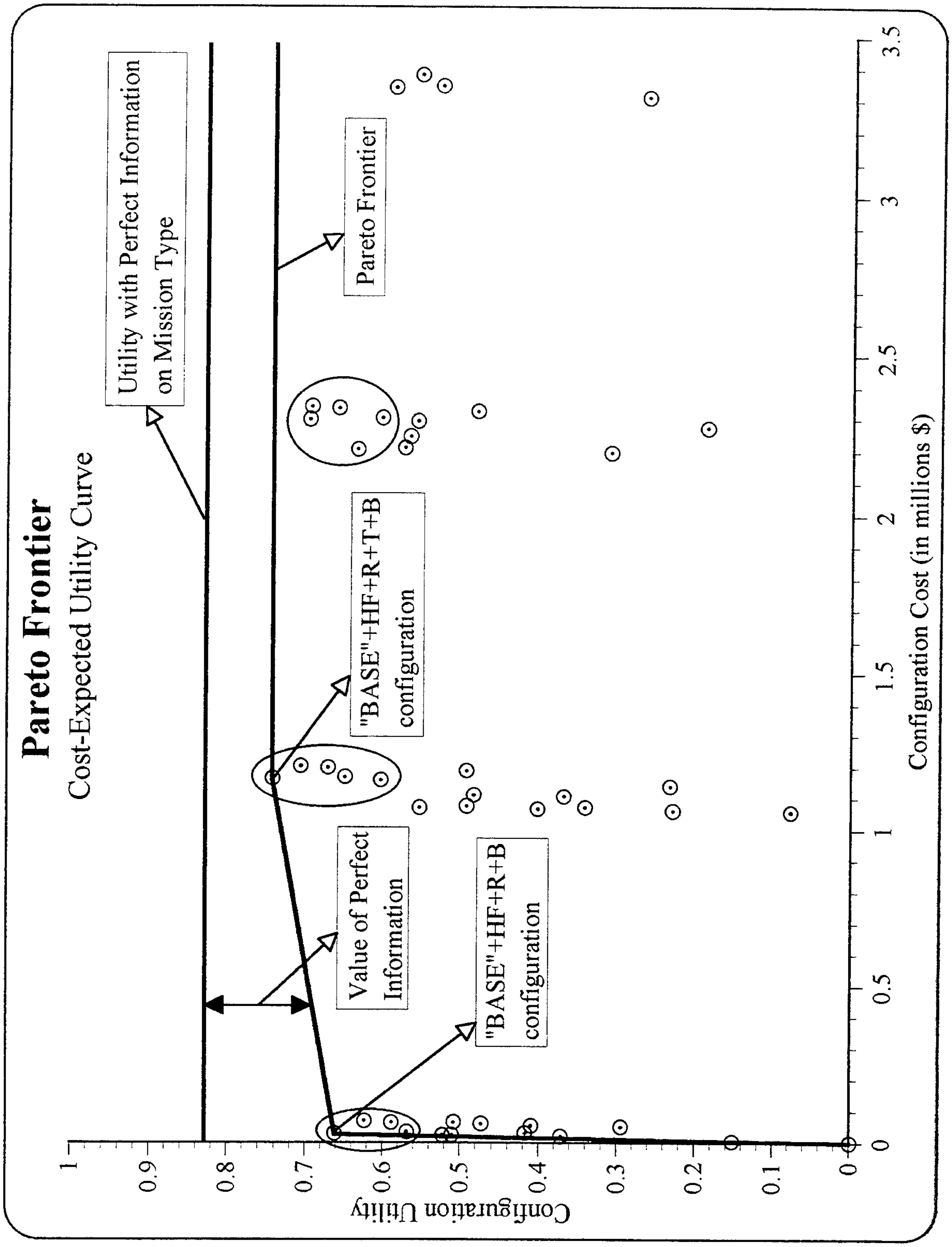

Figure 15. Pareto Frontier for the Configuration Decision Problem

0.826. From **Figure 15**, it can be seen that two configurations create the upper boundary for the Pareto frontier. These configurations, in order of increasing configuration utility, are: (1) the "BASE" helicopter configuration with Hellfire missiles, rockets, and bombs, and (2) the "BASE" helicopter configuration with Hellfire missiles, rockets, a Mk-50 torpedo, and a bomb. From page 11 in **Chapter II**, the "BASE" helicopter configuration consists of a radar, Magnetic Anomaly Detector (MAD), sonobuoys, self-defensive chaff, flares, ship-defensive decoy chaff, a Forward Looking Infrared Radar (FLIR), a Low Light level Television (LLTV), a laser designator, and a 7.62 mm door gun.

The interpretation of the Pareto frontier is straightforward. Any configuration below the Pareto frontier line (also known as the efficient frontier) may not warrant the cost of that configuration for the utility that it provides. In other words, the utility versus cost point for any configuration should lie as close to the efficient frontier as possible in order to realize the most efficient configuration. The following two simple examples illustrate the use of the Pareto frontier plot. The first example will be a budget constrained problem, and the second example will be a maximum utility problem. Suppose the SH-60B is to be configured with some unspecified type of weapons, and an arbitrary maximum of $1.5 million can be spent to provide those weapons. Based on this Pareto frontier, to get the most utility for the money, one of the configurations in the second cost range in **Figure 15** would be appropriate. From the figure, no configuration in the first, third, or fourth cost ranges would be appropriate since the cost for those configurations is either (1) not spending as much of the $1.5 million as was allocated, or (2) the configuration costs more than $1.5 million. In the second example, suppose the SH-60B was to be configured with

weapons that produced a maximum utility. The first, third, and fourth cost ranges produce utilities that are below the maximum on the Pareto frontier. The second cost range, again, has configurations that are fairly high that would be considered. From these two simple examples, it should be seen that, for the values used in this problem, no configuration costing over about $1.2 million should ever be considered for use on the SH-60B, because the cost is too great for the utility that is achieved. On the operational level if there is accountability for allocated funds and "more is better" with respect to available weapons, the decision would clearly be to choose configurations from the first two cost ranges.

For the first, second, and third cost ranges in **Figure 15**, the top configurations have been circled. They have been highlighted because if sensitivity analysis (see **Section C** of **Chapter III** on page 27) is done, any one of these configurations might "take over" as a bounding configuration for the efficient frontier. The four configurations at the first cost range are: the "BASE" helicopter with (1) Hellfire missiles, 2.75 inch rockets, and bombs, (2) Hellfire missiles, forward firing gun, and bombs, (3) 2.75 inch rockets, a forward firing gun, and bombs, and (4) Hellfire missiles and bombs. The five configurations at the second cost range are: the "BASE" helicopter with (1) Hellfire missiles, 2.75 inch rockets, a torpedo, and a bomb,(2) Hellfire missiles, a forward firing gun, a torpedo, and a bomb, (3) 2.75 inch rockets, a forward firing gun, a torpedo, and a bomb, (4) Hellfire missiles, a torpedo, and a bomb, and (5) 2.75 inch rockets, a torpedo, and a bomb. The five configurations at the third cost range are: the "BASE" helicopter with (1) Hellfire missiles, 2.75 inch rockets, and torpedoes, (2) a forward firing gun, and torpedoes, (3) 2.75 inch rockets, a forward firing gun, and torpedoes, (4) 2.75 inch rockets, a Penguin missile, a

torpedo, and a bomb, and (5) Hellfire missiles and torpedoes. The above information suggests that if a low cost configuration is required, then at least the Hellfire missile for the primary weapon stations and bombs for the secondary weapon stations should be included in that configuration. If a configuration cost of less than $1.2 million were required, again, Hellfire missiles, bombs, and torpedoes should be included in that configuration (assuming maximum utility is desired).

Figure 15 also contains another important piece of information, the value of perfect information on mission type. The utility with this perfect information is displayed as the horizontal line at 0.826 of configuration utility. The value of perfect information is the difference of this horizontal line and the Pareto frontier. This difference is the gain in utility that perfect information would provide. This gives the decision maker an idea of how much an accurate forecast of the mission assignment is worth. If this value is great, the cost of obtaining an accurate forecast might be beneficial to the problem. If the value or gain in utility is low, the cost of getting this forecast is probably not beneficial to the problem. The decision maker must decide based on his situation if the difference between the Pareto frontier and the perfect information value for a given cost is large enough to expend additional resources to try and determine the mission assignment.

It should be kept in mind that the above discussion and analysis were done on a subjective problem and therefore the results do not necessarily reflect any current situation. The model created and the procedures presented are, however, directly usable for actual values. The last chapter introduces areas of further study and the conclusion of the thesis.

E. SUMMARY

The decision model solved in this thesis is based on two decision modeling problems: (1) "What should be the SH-60 helicopter's weapons configuration when the mission assigned is not known with certainty at the time the helicopter is configured?" and (2) "What should be the helicopter's weapons configuration given an assigned mission?" These two decision problems are solved in concert with each other to provide the decision maker with quantifiable information on which he can base his decision. Limitations on weapons configuration packages are discussed in **Chapter II**.

In order to solve the decision problems listed above, the helicopter's mission must be defined. The SH-60B's missions are defined by operational and weapon requirements and are broken down into the following six categories: ASW, RSTA, NSFS, CSAR, MCM, and Boarding. It is assumed that when a mission is assigned that a threat particular to that mission is present in the battlespace. **Table 4** on page 35 provides a listing of sample threats and weapons required for each mission. Operationally a mission is either a success or failure. Therefore, a successful mission is defined as completing an assigned mission where at least one of the following situations occurred, (1) a threat was neutralized with weapons before threat weapon engagement occurred, (2) threat engagement was deterred, or (3) no threat contact was made. All other situations are defined as a mission failure.

In order to make a decision about helicopter weapon configurations, some value or utility for each configuration must be determined. Indifference probabilities were used to assign utility to each configuration studied in this thesis. Indifference can best be

understood by an example. Suppose a helicopter was configured to carry Hellfire missiles and a forward firing gun on a RSTA mission, and the aircrew was given the following choice: take a gamble where winning would replace the forward firing gun with Hellfire missiles and losing would remove all weapons from the helicopter or stay with the Hellfire missiles and the forward firing gun. The indifference probability (the utility of the Hellfire missiles and a forward firing gun) is that minimum probability the aircrew would have to have at winning the gamble if they choose to gamble. It should be noted that these indifference probability will be different for every decision maker. In order to minimize inconsistent utility values, consistency and/or logic checks should be performed. Also, the utility value for a weapons package with extraneous weapons (i.e., weapons not used in a particular mission or which do not occupy a weapon station that could be used for weapons for that particular mission) is the same as that same weapons package without extraneous weapons.

The data required to construct the decision model is straightforward but not necessarily easy to obtain. The set definitions for the model are: (1) $\mathcal{C}$, the helicopter configuration as listed in **Table 3** on page 15, (2) $\mathcal{M}^*$, the missions assigned, which are defined as ASW, RSTA, NSFS, CSAR, MCM, Boarding, (3) $\mathcal{X}$, the mission outcome defined as mission success or mission failure, and (4) $\mathcal{R}$, the configuration utility as listed in **Table 5** on page 41. To be able to complete the decision tree necessary for the model, the cost of configuring a helicopter with a particular weapons package, the probability of being assigned a specific mission, and the conditional probability of mission success given

a particular mission and helicopter configuration must be known. With this information, an influence diagram and decision tree can be constructed to solve the model.

The influence diagrams and decision trees are constructed in a time ordered sequence of events, with the decision tree incorporating the required data on appropriate branches. The events used in this model are: (1) the helicopter is configured to fly, (2) a mission is assigned through a tasking order, (3) a mission outcome is realized (this assumes the mission assigned is flown by the helicopter), and (4) the result or utility of the mission is achieved. The influence diagram is constructed to show information on the relationships and interdependencies among the events. An understanding of the influence diagram allows the decision maker to correctly define the problem and helps him visualize graphically how decisions, uncertain events, and outcomes are interrelated. With the influence diagram completed, the decision tree is constructed. The data for each branch is taken from the required data directly. The expected values for each random event in the tree and a maximization at each decision event is calculated. The perfect information problem is now solved to determine the maximum mission utility over all the configurations. This problem is constructed the same as the previous problem, except now the mission is known before the helicopter configuration is done. The perfect information decision tree produced one result that can be compared to the previous problems 44 results. This comparison is displayed in a Pareto frontier graph. From the graph, one can determine the value of accurately forecasting a mission assignment by comparing a configuration utility value with the perfect information utility value. The difference in these two values is the value of knowing the mission. The decision maker can now

graphically see which configurations provide the highest utility, lowest cost, and the value of perfect information on mission type and make an informed decision based on his needs.

Although this model was done with sample values, provided by the author, the reasonable question to ask is "Does the model make sense to the decision maker?" Given the constraints of this thesis, the reasonable probability values, and the consistent utility values for each weapon configuration package, the model showed that the maximum utility with an unknown mission assignment was achieved by the configuration with Hellfire missiles, 2.75 inch rockets, a torpedo, and a 500 lb. bomb. In the author's opinion the logic of having multi-mission capable aircraft available in a timely manner to the battlegroup commander is essential, and an SH-60B configured with these weapons can perform all nine mission types (i.e., ASW, RSTA, NSFS, CSAR, MCM, Boarding, ASST, ECM, and "Other") that are assigned it. Therefore, if the mission is not known and the constraints of this thesis are applicable, then the model has produced a good weapon combination to adequately perform any assigned mission.

V. CONCLUSIONS AND RECOMMENDATIONS

With the shift in the national military strategy from global threat to a regional threat, the littoral environment has become the focus of the U.S. naval forces. The SH-60B LAMPS Mk III is a versatile asset available to assist the battlegroup commander in battlespace dominance in a littoral warfare scenario. An effective weapons configuration of the SH-60B helicopter is necessary for it to be a useful asset to the battlegroup commander. This thesis has provided a decision aid model to allow for the effective weapons configuration for the SH-60B helicopter. With the understanding that every warfare situation is different and dynamic, no single weapon configuration can be "perfect" for all scenarios. This model was developed to allow the decision maker (e.g., the person or persons making the helicopter weapon configuration decisions) to make informed weapon configuration decisions based on the current tactical situation. The influence diagrams and the decision trees, the first steps in constructing the model, would typically be done in a pre-planning stage (i.e., before the SH-60B would be in theater). Obtaining or developing the required data (i.e., the utility values for each outcome, the conditional probability values for a successful engagement given a mission and configuration, and the probability of being assigned a particular mission) and solving the decision model would typically be done when the helicopter would be in theater.

The sample problem solved in this thesis is a typical problem. Although the probability values and the utility values were synthetically generated by the author, the

results provide an interesting look into the weapon configurations of the SH-60B helicopter. If the reader accepts the limitations and assumptions of the thesis, the SH-60B can be configured to adequately provide support for all of its assigned mission areas and still maintain a high utility rating, close to that utility rating of perfect information if the mission was known. Although beyond the scope of this thesis, the model above is or can be expanded as described below.

In **Chapter IV**, the problem of "how to configure the SH-60B" was addressed. That problem is now expanded to cover a more complex weapons configuration problem. In the problem addressed in this thesis, the threat or target of the weapons was assumed either present or not present and if present had no role in the outcome of the problem and no intelligence information on the threat in the battlespace was available. To approximate the interaction of a threat in the battlespace was more closely, the influence diagram in **Figure 16** is thought more appropriate. This influence diagram differs from the influence diagram in **Figure 10** on page 47 in that a threat forecast chance node and a mission forecast chance node and a threat chance node are included. The threat forecast is an estimate of what threats will be in the battlespace and the threat is the actual threat, if any, the helicopter encounters during the course of its mission. The mission forecast is an estimate based on the available information of what the mission will be. On the initial observance of the influence diagram, the mission chance node appears to be an unnecessary piece of information. But the intricacies of the actual problem insist that it remain in the influence diagram, because the mission assigned to a helicopter may not coincide with the threat that is faced in the helicopter's area of operation. Also the mission forecast may be unable

to predict accurately the mission. If this is the case, the configuration decision still has knowledge of the threat forecast, and the decision of how to configure the helicopter can be made to satisfy both the mission assignment requirements and applicable weapons to deter the proposed threat in the helicopter's area of operation. For example, if a patrol boat

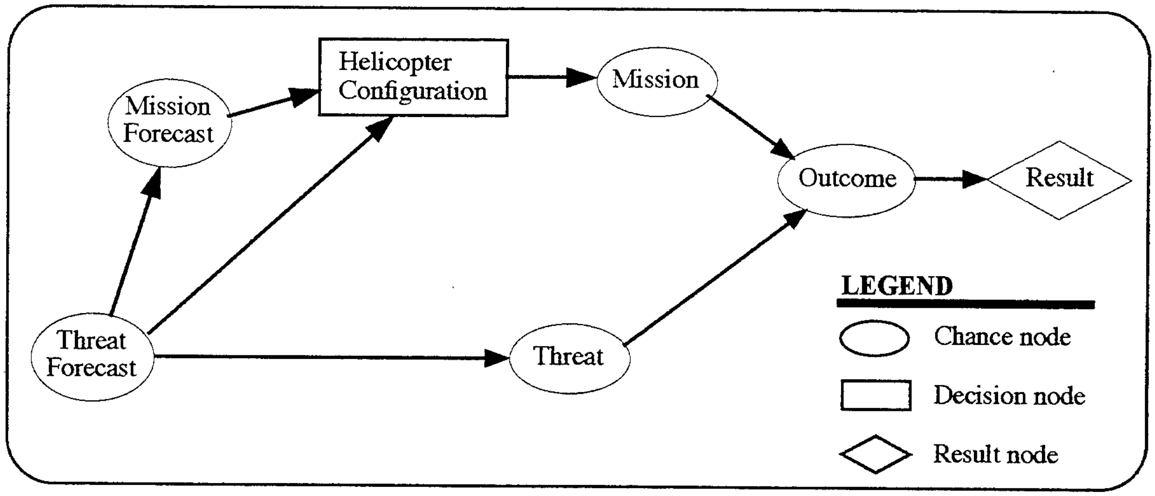

Figure 16. Real World Influence Diagram for SH-60B Weapon Configuration

is forecast to be in the area and the helicopter is assigned given a mission forecast of ASW, the decision of how to configure the helicopter must satisfy the mission forecast assignment and the configuration may also contain weapons that are appropriate for a patrol boat encounter. This configuration flexibility is necessary because a planned mission is not necessarily the only mission a helicopter will perform in a sortie. The arcs in the influence diagram are explained below.

The directed arc between the threat forecast and the mission forecast chance node indicates the threat forecast is known prior to accessing the probability distribution of the mission forecast chance node and the outcome of the mission forecast has some type of

dependence on the outcome of the threat forecast. The directed arc between the threat forecast chance node and the configuration decision node indicates the outcome of the threat forecast is known before the configuration decision is made and that outcome has some influence on the decision made. The directed arc between the mission forecast chance node and the configuration decision indicates an influence in the configuration decision by the mission forecast outcome and that outcome is known before the decision is made. The arc between the threat forecast and the threat chance nodes indicates a conditional dependence of the threat on the threat forecast, and the threat forecast is known before the threat outcome is accessed. The directed arc between the configuration decision node and the mission chance node indicate a dependence of the configuration decision and the actual mission assigned. The helicopter configuration is known before the mission assignment is made. The directed arc between the mission chance node and the outcome chance node indicate the mission assignment is known before the outcome of the mission is known, and that mission assignment has some influence on the outcome of the mission. The arc between the threat and outcome chance nodes indicates the outcome of the mission is conditional dependent on the outcome of the threat, and the outcome of the threat is known before the probability distribution of the outcome of the mission is accessed. The directed arc between the outcome chance node and the result node shows all the possible result that may occur in the problem.

This is only one of a variety of influence diagrams to model a realistic configuration problem. It contains all the essential elements of the problem, although many variations can be constructed. Since an attempt to solve this particular problem goes beyond the

scope of this thesis, it is left for further study. Other areas for further study include: (1) how does one determine the probability of assigning a mission. Is it based on passed experience or the tactical situation? Once those probabilities are determined, do they make sense according to the tactical scenario? Can they be produced by developing some type of simulation or algorithm? and (2) How are the conditional probabilities determined? The same questions above can be asked of this question.

As new weapon systems become available to the SH-60B helicopter and the need for effective assets in littoral environments increases, the SH-60B must provide an efficient and capable weapon system that is able to deal with the littoral threat environment. Decision aids, such as the model developed in this thesis, provide a way of determined effective and efficient weapon configurations based on the needs of the battlegroup commander. To this extent and with the assumptions and probability values of this thesis accepted, the result of this decision model is to configure a "BASE" (see page 11) the SH-60B LAMPS Mk III with Hellfire missiles, 2.75 inch rockets, an Mk 50 torpedo, and a bomb. This configuration allows the SH-60B to perform any and all of its missions areas without a weapons reconfiguration when the assigned mission for a particular flight is unknown.

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APPENDIX A: SH-60B OPERATIONAL CAPABILITIES

The "Mission Area" acronym used in this appendix are defined as follows:

- AAW: Anti-Air Warfare,
- AMW: Amphibious Warfare,
- ASU: Anti-Surface Ship Warfare,
- ASW: Anti-Submarine Warfare,
- CCC: Command, Control, and Communications,
- ELW: Electronic Warfare,
- FSO: Fleet Support Operations,
- INT: Intelligence,
- LOG: Logistics,
- MIW: Mine Warfare,
- MOB: Mobility,
- NCO: Non-Combatant Operations.

TABLE A1 . Operational Capabilities and Sub-Capabilities for the SH-60B Helicopter [Ref. 4]

Mission Areas	Capability and Sub-Capability Definitions
AAW	➢ Detect, identify, and track air targets ◆ recognize by sight friendly and enemy aircraft which may be encountered in expected operation areas ◆ <u>Classified</u>
AMW	➢ Support/conduct Naval Gunfire Support (NGFS) against designated targets in support of an amphibious operation ◆ conduct spotting for naval gunfire and artillery
ASU	➢ Engage surface targets during battle group (BG) operations in cooperation with other forces ◆ operate in direct support of surface forces ◆ engage surface targets within assigned antisurface sector ➢ Support antisurface ship defense of a geographical area (e.g., zone or barrier) in cooperation with other forces

TABLE A1 . Operational Capabilities and Sub-Capabilities for the SH-60B Helicopter [Ref. 4] (Continued)

Mission Areas	Capability and Sub-Capability Definitions
ASU	➢ Detect identify, localize, and track surface ship targets ◆ detect, localize, and track surface contacts with radar ◆ detect and track surface contacts visually ◆ identify surface contracts ◆ two <u>classified</u> sub-capabilities ➢ Conduct attacks on surface ships using air-launched armament ◆ attack surface ships using nuclear or conventional armament in all weather environments: (LIMITED) conventional only ◆ attack surface ships using conventional armament in a day visual environment ◆ attack surface ships using conventional armament in a night visual environment ◆ attack surface ships using air-to-surface guided missiles or anti-radiation weapons systems: (LIMITED) guided missiles only ◆ evade hostile surface-to-air threats ◆ conduct air-to-surface conventional attacks on surface ships during all weather conditions, day and night under external control ➢ Conduct airborne operations in support of antisurface attack operations ◆ provide over-the-horizon (OTH) targeting information in support of air attack operations ◆ <u>Classified</u> ➢ Perform duties of Aircraft Control Unit (ACU) for aircraft involved in ASUW operations
ASW	➢ Conduct airborne antisubmarine operations ◆ conduct day and night, all-weather, airborne antisubmarine cyclic operations ◆ provide information to surface units utilizing data link

TABLE A1 . Operational Capabilities and Sub-Capabilities for the SH-60B Helicopter [Ref. 4] (Continued)

Mission Areas	Capability and Sub-Capability Definitions
ASW	➢ Engage submarines in cooperation with other forces ◆ operate as a member of a combined surface and aviation Surface Action Unit (SAU) ◆ operate in direct support of surface forces ◆ detect, localize, and track subsurface (periscope depth) contacts visually or with radar ◆ six <u>classified</u> sub-capabilities ➢ Engage submarines with antisubmarine armament ◆ attack with torpedoes ◆ attack with air-launched missiles
CCC	➢ Coordinate and control the operations of the task organization or functional force to carry out assigned missions ◆ function as on-scene commander for a Search-and-Rescue (SAR) operation ◆ function as LAMPS Element Coordinator (LEC) for force or sector ➢ Provide own unit's command and control functions ◆ provide all necessary personnel services, programs, and facilities to safeguard classified material and information ◆ carry out emergency destruction of classified matter and equipment rapidly and efficiently ◆ employ Identification Friend or Foe/Selective Identification feature (IFF/SIF) including secure IFF mode 4 ➢ Provide communications for own unit ◆ provide tactical voice communications ◆ maintain automatic relay communications ➢ Relay naval communications ◆ relay electronic communications
ELW	➢ All capabilities and sub-capabilities are <u>classified</u>

TABLE A1 . Operational Capabilities and Sub-Capabilities for the SH-60B Helicopter [Ref. 4] (Continued)

Mission Areas	Capability and Sub-Capability Definitions
INT	➢ Classified ➢ Conduct surveillance and reconnaissance ◆ conduct overt surveillance and reconnaissance operations ◆ classified ➢ Support/conduct airborne reconnaissance ◆ support/conduct unarmed reconnaissance (weather, visual, Battle Damage Assessment (BDA), etc.) ◆ recognize by sight friendly and enemy aircraft, ships and submarines which may be encountered in the expected operations areas
FSO	➢ Support/conduct SAR operations in a combat/noncombat environment ◆ support/conduct combat/noncombat SAR operations by fixed or rotary wing aircraft: (LIMITED) overwater: day/night LOW threat; overland: day only Non-Hostile threat ◆ recover man overboard ◆ support/perform planeguard/lifeguard functions ◆ conduct SAR operations (including operation involving submarine disasters/rescues) ◆ conduct general surveillance ◆ report situation assessment ◆ coordinate SAR operations ◆ conduct multiunit SAR operations ◆ conduct combat SAR operations in support of battle force operations by special warfare forces in a hostile environment: (LIMITED) overwater day/night LOW threat ➢ Provide first aid assistance ◆ train assigned personnel in first aid, self, and buddy aid procedures
LOG	➢ Provide airlift of cargo and personnel ◆ provide Vertical Replenishment (VERTREP) ◆ provide Medical Evacuation (MEDEVAC)

TABLE A1 . Operational Capabilities and Sub-Capabilities for the SH-60B Helicopter [Ref. 4] (Continued)

Mission Areas	Capability and Sub-Capability Definitions
MIW	➢ Conduct mine neutralization/destruction ◆ provide support for embarked EOD/SEAL teams
NCO	➢ Provide administrative and supply support for own unit ◆ provide supply support services ◆ provide clerical services ◆ provide personnel for area command security ◆ provide personnel for fuels support ➢ Provide upkeep and maintenance of own unit ◆ provide organizational level maintenance ➢ Provide emergency/disaster assistance ◆ provide disaster assistance and evacuation ➢ Support/provide for the evacuation of noncombatant personnel in areas of civil or international crisis ◆ support/conduct helicopter/boat evacuation of noncombatant personnel as directed by higher authority from areas of civil or international crisis ◆ provide transportation for evacuees to designated safe havens or onward processing centers ➢ Conduct maritime law enforcement operations ◆ detect and identify noncombatant vessels ◆ provide assistance to other law enforcement forces ◆ conduct drug traffic suppression and interdiction operations
MOB	➢ Support/provide safe, flyable aircraft for all weather operations ➢ Prevent and control damage ◆ maintain security against unfriendly acts ➢ Refuel in the air ◆ receive fuel in day/night ship-to-air refueling

TABLE A1 . Operational Capabilities and Sub-Capabilities for the SH-60B Helicopter [Ref. 4] (Continued)

Mission Areas	Capability and Sub-Capability Definitions
MOB	➢ Perform seamanship, airmanship, and navigation tasks ◆ navigate under all conditions of geographic location, weather, and visibility ◆ operate day and night and under all weather conditions ➢ Operate from a ship ◆ operate from and aircraft carrier ◆ operate from a ship with helicopter platform ➢ Maintain mount-out capabilities ◆ deploy with organic allowance within designated time period ◆ mount-out selected elements/detachments ◆ maintain capability for rapid airlift of unit/detachment as directed ➢ Maintain the health and well-being of the crew ◆ maintain the environment to ensure the protection of personnel from over exposure to hazardous levels of radiation, temperature, noise, vibration, and toxic substances per current standards ◆ monitor to ensure that habitability is consistent with approved habitability procedures and standards

APPENDIX B: MISSION WEAPON CONFIGURATIONS

The SH-60B weapon configurations are grouped by missions and list only those configurations where appropriate combinations of weapons required (see Table 4 on page 35) are used. Table acronym meanings are:

- BASE : Base configuration of the SH-60B which includes a radar, Magnetic Anomaly Detector (MAD), sonobuoys, self defensive chaff, flares, a Forward Looking Infrared Radar (FLIR), ship decoy chaff, a Low Light Television (LLTV), laser designator, and a 7.62mm Door Gun,
- HF : Hellfire missiles,
- R : 2.75 inch rockets,
- FF : a Forward firing gun,
- P : Penguin missile,
- T : Torpedoes, and
- B : 500 pound gravity bombs.

TABLE B1. Mission-Required Weapon Configurations For SH-60B

Configuration	Mission	Configuration	Mission
BASE + T	ASW	BASE + HF	RSTA
BASE + B	ASW	BASE + HF + R	RSTA
BASE + T + B	ASW	BASE + HF + FF	RSTA
BASE + HF +T	ASW	BASE + HF + P	RSTA
BASE + HF + R + T	ASW	BASE + R + FF	RSTA
BASE + HF + FF + T	ASW	BASE + R + P	RSTA
BASE + HF + P + T	ASW	BASE + FF + P	RSTA
BASE + R + FF + T	ASW	BASE + R	RSTA
BASE + R + P + T	ASW	BASE + FF	RSTA
BASE + FF + P + T	ASW	BASE + P	RSTA
BASE + R + T	ASW	BASE + HF + T	RSTA
BASE + FF + T	ASW	BASE + HF + R + T	RSTA
BASE + P + T	ASW	BASE + HF + FF + T	RSTA

TABLE B1. **Mission-Required Weapon Configurations For SH-60B** (Continued)

Configuration	Mission	Configuration	Mission
BASE + HF + T + B	ASW	BASE + HF + P + T	RSTA
BASE + HF + R + T + B	ASW	BASE + R + FF + T	RSTA
BASE + HF + FF + T + B	ASW	BASE + R + P + T	RSTA
BASE + HF + P + T + B	ASW	BASE + FF + P + T	RSTA
BASE + R + FF + T + B	ASW	BASE + R + T	RSTA
BASE + R + P + T + B	ASW	BASE + FF + T	RSTA
BASE + FF + P + T + B	ASW	BASE + P + T	RSTA
BASE + R + T + B	ASW	BASE + HF + T + B	RSTA
BASE + FF + T + B	ASW	BASE + HF + R + T + B	RSTA
BASE + P + T + B	ASW	BASE + HF + FF + T + B	RSTA
BASE + HF + B	ASW	BASE + HF + P + T + B	RSTA
BASE + HF + R + B	ASW	BASE + R + FF + T + B	RSTA
BASE + HF + FF + B	ASW	BASE + R + P + T + B	RSTA
BASE + HF + P + B	ASW	BASE + FF + P + T + B	RSTA
BASE + R + FF + B	ASW	BASE + R + T + B	RSTA
BASE + R + P + B	ASW	BASE + FF + T + B	RSTA
BASE + FF + P + B	ASW	BASE + P + T + B	RSTA
BASE + R + B	ASW	BASE + HF + B	RSTA
BASE + FF + B	ASW	BASE + HF + R + B	RSTA
BASE + P + B	ASW	BASE + HF + FF + B	RSTA
		BASE + HF + P + B	RSTA
		BASE + R + FF + B	RSTA
		BASE + R + P + B	RSTA
		BASE + FF + P + B	RSTA
		BASE + R + B	RSTA
		BASE + FF + B	RSTA
		BASE + P + B	RSTA
BASE + HF	NSFS	BASE + HF	CSAR
BASE + HF + R	NSFS	BASE + HF + R	CSAR
BASE + HF + FF	NSFS	BASE + HF + FF	CSAR
BASE + HF + P	NSFS	BASE + HF + P	CSAR
BASE + R + FF	NSFS	BASE + R + FF	CSAR
BASE + R + P	NSFS	BASE + R + P	CSAR

TABLE B1. Mission-Required Weapon Configurations For SH-60B (Continued)

Configuration	Mission	Configuration	Mission
BASE + FF + P	NSFS	BASE + FF + P	CSAR
BASE + R	NSFS	BASE + R	CSAR
BASE + FF	NSFS	BASE + FF	CSAR
BASE + HF + T	NSFS	BASE + HF + T	CSAR
BASE + HF + R + T	NSFS	BASE + HF + R + T	CSAR
BASE + HF + FF + T	NSFS	BASE + HF + FF + T	CSAR
BASE + HF + P + T	NSFS	BASE + HF + P + T	CSAR
BASE + R + FF + T	NSFS	BASE + R + FF + T	CSAR
BASE + R + P + T	NSFS	BASE + R + P + T	CSAR
BASE + FF + P + T	NSFS	BASE + FF + P + T	CSAR
BASE + R + T	NSFS	BASE + R + T	CSAR
BASE + FF + T	NSFS	BASE + FF + T	CSAR
BASE + HF + T + B	NSFS	BASE + HF + T + B	CSAR
BASE + HF + R + T + B	NSFS	BASE + HF + R + T + B	CSAR
BASE + HF + FF + T + B	NSFS	BASE + HF + FF + T + B	CSAR
BASE + HF + P + T + B	NSFS	BASE + HF + P + T + B	CSAR
BASE + R + FF + T + B	NSFS	BASE + R + FF + T + B	CSAR
BASE + R + P + T + B	NSFS	BASE + R + P + T + B	CSAR
BASE + FF + P + T + B	NSFS	BASE + FF + P + T + B	CSAR
BASE + R + T + B	NSFS	BASE + R + T + B	CSAR
BASE + FF + T + B	NSFS	BASE + FF + T + B	CSAR
BASE + HF + B	NSFS	BASE + HF + B	CSAR
BASE + HF + R + B	NSFS	BASE + HF + R + B	CSAR
BASE + HF + FF + B	NSFS	BASE + HF + FF + B	CSAR
BASE + HF + P + B	NSFS	BASE + HF + P + B	CSAR
BASE + R + FF + B	NSFS	BASE + R + FF + B	CSAR
BASE + R + P + B	NSFS	BASE + R + P + B	CSAR
BASE + FF + P + B	NSFS	BASE + FF + P + B	CSAR
BASE + R + B	NSFS	BASE + R + B	CSAR
BASE + FF + B	NSFS	BASE + FF + B	CSAR

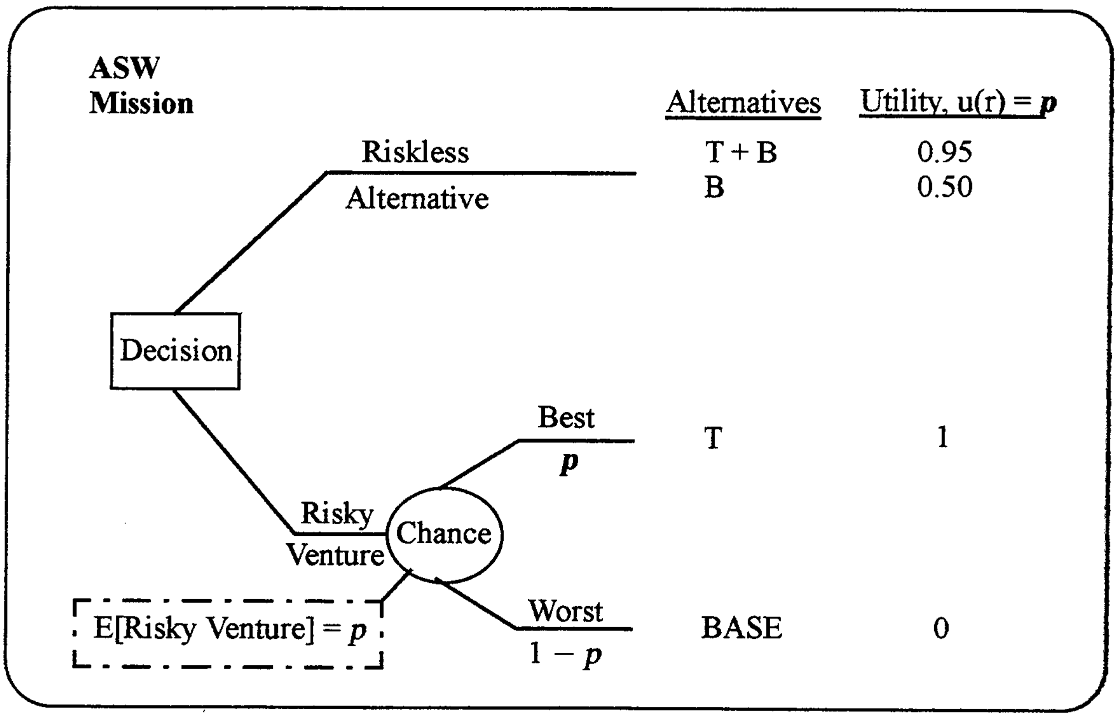
TABLE B1. **Mission-Required Weapon Configurations For SH-60B** (Continued)

Configuration	Mission	Configuration	Mission
BASE + B	MCM	BASE + HF + R	Boarding
BASE + T + B	MCM	BASE + HF + FF	Boarding
BASE + HF + T + B	MCM	BASE + R + FF	Boarding
BASE + HF + R + T + B	MCM	BASE + R + P	Boarding
BASE + HF + FF + T + B	MCM	BASE + FF + P	Boarding
BASE + HF + P + T + B	MCM	BASE + R	Boarding
BASE + R + FF + T + B	MCM	BASE + FF	Boarding
BASE + R + P + T + B	MCM	BASE + HF + R + T	Boarding
BASE + FF + P + T + B	MCM	BASE + HF + FF + T	Boarding
BASE + R + T + B	MCM	BASE + R + FF + T	Boarding
BASE + FF + T + B	MCM	BASE + R + P + T	Boarding
BASE + P + T + B	MCM	BASE + FF + P + T	Boarding
BASE + HF + B	MCM	BASE + R + T	Boarding
BASE + HF + R + B	MCM	BASE + FF + T	Boarding
BASE + HF + FF + B	MCM	BASE + HF + R + T + B	Boarding
BASE + HF + P + B	MCM	BASE + HF + FF + T + B	Boarding
BASE + R + FF + B	MCM	BASE + R + FF + T + B	Boarding
BASE + R + P + B	MCM	BASE + R + P + T + B	Boarding
BASE + FF + P + B	MCM	BASE + FF + P + T + B	Boarding
BASE + R + B	MCM	BASE + R + T + B	Boarding
BASE + FF + B	MCM	BASE + FF + T + B	Boarding
BASE + P + B	MCM	BASE + HF + R + B	Boarding
BASE + HF + FF	MCM	BASE + HF	Boarding
BASE + R + FF	MCM	BASE + HF + P	Boarding
BASE + FF + P	MCM	BASE + HF + T	Boarding
BASE + FF	MCM	BASE + HF + P + T	Boarding
BASE + HF + FF + T	MCM	BASE + HF + T + B	Boarding
BASE + R + FF + T	MCM	BASE + HF + P + T + B	Boarding
BASE + FF + P + T	MCM	BASE + HF + B	Boarding
BASE + FF + T	MCM	BASE + HF + FF + B	Boarding
		BASE + HF + P + B	Boarding
		BASE + R + FF + B	Boarding
		BASE + R + P + B	Boarding
		BASE + FF + P + B	Boarding
		BASE + FF + B	Boarding
		BASE + R + B	Boarding

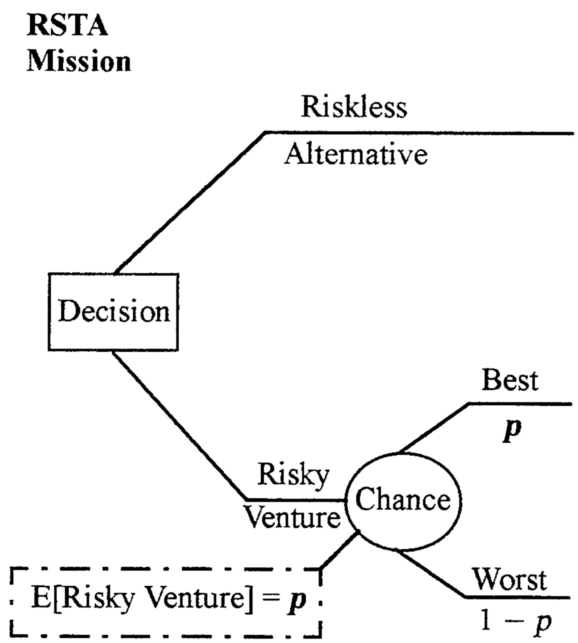
APPENDIX C: MISSION DECISION SAPLINGS

This appendix lists the decision saplings, for each mission, used to determine the indifference probabilities for the configuration-mission combinations. The utility values are shown for every weapon combination for a mission. **Table 4** of **Chapter IV** identifies the which weapons are available for each mission. **Table 5** of **Chapter IV** show the summary listing of these results.

The ASW decision sapling is:

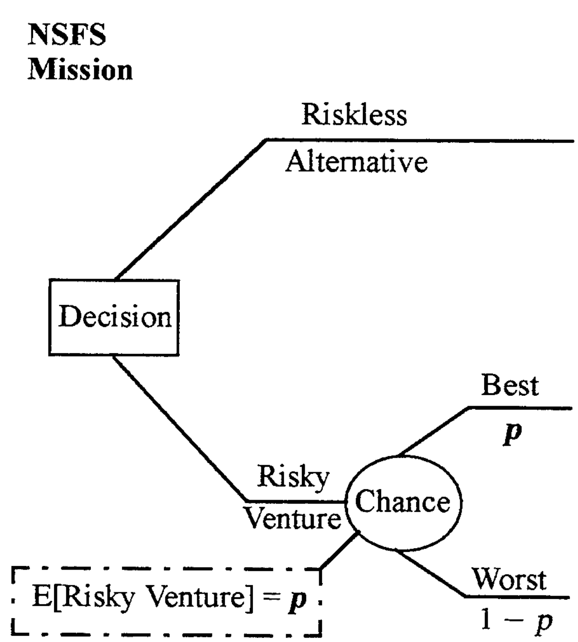


The RSTA decision sapling is:



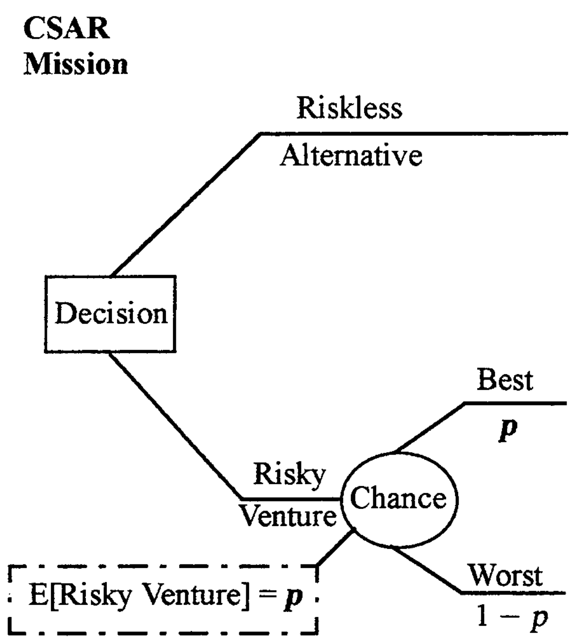
Alternatives	Utility, u(r) = ***p***
R	0.80
P	0.75
FF	0.50
HF + R	0.98
HF + P	0.95
HF + FF	0.92
R + P	0.88
R + FF	0.85
P + FF	0.78
HF	1
BASE	0

The NSFS decision sapling is:



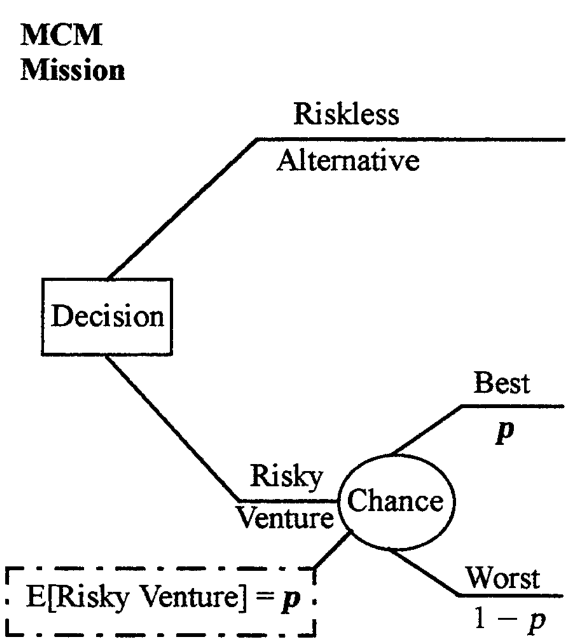
Alternatives	Utility, u(r) = ***p***
R	0.75
FF	0.65
HF + R	0.95
HF + P	0.70
HF + FF	0.90
R + P	0.68
R + FF	0.85
P + FF	0.65
HF	1
BASE	0

The CSAR decision sapling is:



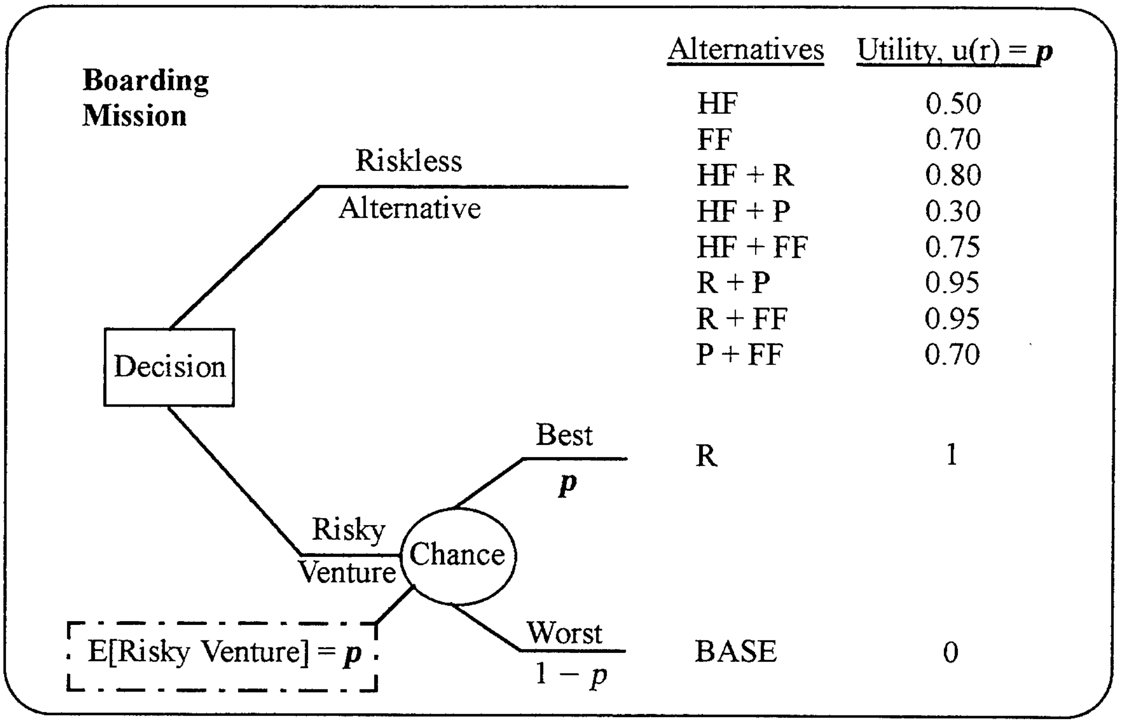
Alternatives	Utility, u(r) = p
R	0.70
FF	0.60
HF	0.75
HF + P	0.72
HF + FF	0.85
R + P	0.65
R + FF	0.75
P + FF	0.60
HF + R	1
BASE	0

The MCM decision sapling is:



Alternatives	Utility, u(r) = p
B	0.98
FF	0.50
T + B	0.90
T + B + FF	0.95
B + FF	1
BASE	0

The Boarding decision sapling is:



APPENDIX D: DECISION TREE SPREADSHEET

This appendix contains the output of an Excel™ spreadsheet. The spreadsheet is broken down into five tables based on information content. **Table D1** lists the cost for each of the 44 configurations. It also lists the number of weapons or weapon kits (a pack of weapons: a Hellfire kit = 4 missiles and a 2.75 inch rocket kit = 19 rockets, all other weapons are number of weapons) for each configuration. The columns are described below:

- Column 1: The name of the configuration.
- Column 2: The cost for each configuration.
- Column 3: The number of weapons or kits associated with each configuration. If only one weapon is in the configuration, then this number is the number of weapons or kits of that weapon. If two weapons are in a configuration, the a slash "/" separates the quantity of weapons or kits for each weapon. If more than three weapons are on a configuration, then the quantities of the primary weapons are listed first with a slash separating the two different weapons, then a space and the secondary weapons are listed second and quantities of different weapons are separated by a slash. For example, the configuration "BASE"+HF+FF+T+B has one Hellfire kit, one forward firing gun, one torpedo, and one bomb will be listed as "1/1 1/1."

Table D1. Configuration Costs

Configuration	Cost	Number of kits or weapons
BASE	0	0
BASE+HF	0.03	2
BASE+HF+R	0.025	1/1
BASE+HF+FF	0.065	1/1
BASE+HF+P	1.072	1/1
BASE+R+FF	0.06	1/1
BASE+R+P	1.067	1/1
BASE+FF+P	1.107	1/1
BASE+R	0.02	2
BASE+FF	0.05	1
BASE+P	1.057	1
BASE+T	2.274	2
BASE+B	0.004	2
BASE+T+B	1.139	1/1
BASE+HF+T	2.304	2/2
BASE+HF+R+T	2.299	1/1 2
BASE+HF+FF+T	2.339	1/1 2
BASE+HF+P+T	3.346	1/1 2
BASE+R+FF+T	2.334	1/1 2
BASE+R+P+T	3.341	1/1 2
BASE+FF+P+T	3.381	1/1 2
BASE+R+T	2.294	1/1 2
BASE+FF+T	2.324	1/1 2
BASE+P+T	3.31	1/1 2
BASE+HF+T+B	1.169	1/1 1/1
BASE+HF+R+T+B	1.164	1/1 1/1
BASE+HF+FF+T+B	1.204	1/1 1/1
BASE+HF+P+T+B	2.211	1/1 1/1
BASE+R+FF+T+B	1.199	1/1 1/1
BASE+R+P+T+B	2.206	1/1 1/1
BASE+FF+P+T+B	2.246	1/1 1/1
BASE+R+T+B	1.159	1/1 1/1
BASE+FF+T+B	1.189	1/1 1/1
BASE+P+T+B	2.196	1/1 1/1
BASE+HF+B	0.034	2/2
BASE+HF+R+B	0.029	1/1 2
BASE+HF+FF+B	0.069	1/1 2

Table D1. Configuration Costs

Configuration	Cost	Number of kits or weapons
BASE+HF+P+B	1.076	1/1 2
BASE+R+FF+B	0.064	1/1 2
BASE+R+P+B	1.071	1/1 2
BASE+FF+P+B	1.111	1/1 2
BASE+R+B	0.024	1/1 2
BASE+FF+B	0.054	1/1 2
BASE+P+B	1.061	1/1 2

Table D2 in this appendix lists the values in tabular form computed for all the branches of the decision tree in **Figure 11** on page 49. As explained in the text, each row represents a specific outcome in the decision tree. Since the outcome chance node in the decision tree shown in **Figure 11** has only two possible outcomes, and each of those two outcomes relates to only one mission-configuration combination, every two rows in **Table D2** corresponds to one outcome chance node. To simplify the table, the mission-configuration combination is listed only once for each outcome chance node. The columns are explained below:

- Column 1: **Mission, i** ... The six missions assigned to the SH–60B in this thesis (ASW, RSTA, NSFS, CSAR, MCM, and Boarding). The ASST, ECM, and Utility missions are shown in **Table D3.**
- Column 2: **Helicopter Configuration, j** ... The 44 weapon configurations listed for each of the six missions. **Appendix B** lists the applicable mission-configuration combinations.
- Column 3: **Config. Cost (million $)** ... The configuration cost in millions of dollars as determined from Reference 10 and 11, and discussed in **Chapter IV** on page 44. **Table D4** in this appendix lists the costs for each of the 44 configurations.
- Column 4: **Utility, u(r)** ... The utility of each mission and configuration combination is shown in **Appendix C** and summarized in **Table 5** on page 41.
- Column 5: **Normalized p(i)** ... The probability of being assigned a particular mission. This value was determined by uniform random number generator whose values are listed in **Table D4** of this appendix. The probabilities of the missions that required no weapons (ASST, ECM, Utility) were not used as explained in the text on page 34. The remaining probabilities were normalized to one. The values for the ASST, ECM and Utility missions, as shown in **Table D3**, are the probabilities when using all nine missions.
- Column 6: **p(success| j, i)** ... These are the probabilities of mission success (the labeled mission-configuration row) and mission failure (the unlabeled mission-configuration row) for a given mission and configuration. These values are subjective assignments based on the perceived mission and configuration success by the author.

- Column 7: **col 4×col 5×col 6** ... The product of columns 4, 5, and 6 and used in column 8 calculations.
- Column 8: **E[config]** ... The expected value of each configuration, which is determined by summing the expected value of each configuration type over all the missions. The **col 4×col 5×col 6** column was the source for the expected values of the configurations.
- Column 9: **Pre–Config. Utility** ... The configuration utility calculated for each possible outcome. Column 4 times column 6 yields this result.
- Column 10: **Config. Utility, u[config]** ... The configuration utility for each configuration and mission combination, where each entry is the sum of the corresponding labeled and unlabeled rows of column 9.

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success|j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
ASW	BASE	0	0	0.20713	0.25	0	0	0	0
			0	0.20713	0.75	0	0		0
ASW	BASE+HF	0.03	0	0.20713	0.25	0	0	0	0.417291
			0	0.20713	0.75	0	0		0
ASW	BASE+HF+R	0.025	0	0.20713	0.25	0	0	0	0.51040662
			0	0.20713	0.75	0	0		0
ASW	BASE+HF+FF	0.065	0	0.20713	0.25	0	0	0	0.50805995
			0	0.20713	0.75	0	0		0
ASW	BASE+HF+P	1.072	0	0.20713	0.25	0	0	0	0.3417732
			0	0.20713	0.75	0	0		0
ASW	BASE+R+FF	0.06	0	0.20713	0.25	0	0	0	0.47302015
			0	0.20713	0.75	0	0		0
ASW	BASE+R+P	1.067	0	0.20713	0.25	0	0	0	0.4026688
			0	0.20713	0.75	0	0		0
ASW	BASE+FF+P	1.107	0	0.20713	0.25	0	0	0	0.36867902
			0	0.20713	0.75	0	0		0
ASW	BASE+R	0.02	0	0.20713	0.25	0	0	0	0.3714094
			0	0.20713	0.75	0	0		0
ASW	BASE+FF	0.05	0	0.20713	0.25	0	0	0	0.29443932
			0	0.20713	0.75	0	0		0
ASW	BASE+P	1.057	0	0.20713	0.25	0	0	0	0.0776205
			0	0.20713	0.75	0	0		0
ASW	BASE+T	2.274	1	0.20713	0.9	0.186417	0.9	0.9	0.186417
			0	0.20713	0.1	0	0		0
ASW	BASE+B	0.004	0.5	0.20713	0.6	0.062139	0.3	0.3	0.15126216
			0	0.20713	0.4	0	0		0
ASW	BASE+T+B	1.139	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.23244595
			0	0.20713	0.2	0	0		0
ASW	BASE+HF+T	2.304	1	0.20713	0.9	0.186417	0.9	0.9	0.603708
			0	0.20713	0.1	0	0		0
ASW	BASE+HF+R+T	2.299	1	0.20713	0.9	0.186417	0.9	0.9	0.69682362
			0	0.20713	0.1	0	0		0
ASW	BASE+HF+FF+T	2.339	1	0.20713	0.9	0.186417	0.9	0.9	0.69447695
			0	0.20713	0.1	0	0		0
ASW	BASE+HF+P+T	3.346	1	0.20713	0.9	0.186417	0.9	0.9	0.5281902
			0	0.20713	0.1	0	0		0
ASW	BASE+R+FF+T	2.334	1	0.20713	0.9	0.186417	0.9	0.9	0.65943715
			0	0.20713	0.1	0	0		0
ASW	BASE+R+P+T	3.341	1	0.20713	0.9	0.186417	0.9	0.9	0.5890858
			0	0.20713	0.1	0	0		0
ASW	BASE+FF+P+T	3.381	1	0.20713	0.9	0.186417	0.9	0.9	0.55509602
			0	0.20713	0.1	0	0		0
ASW	BASE+R+T	2.294	1	0.20713	0.9	0.186417	0.9	0.9	0.5578264

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success[j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
			0	0.20713	0.1	0	0		0
ASW	BASE+FF+T	2.324	1	0.20713	0.9	0.186417	0.9	0.9	0.48085632
			0	0.20713	0.1	0	0		0
ASW	BASE+P+T	3.31	1	0.20713	0.9	0.186417	0.9	0.9	0.2640375
			0	0.20713	0.1	0	0		0
ASW	BASE+HF+T+B	1.169	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.64973695
			0	0.20713	0.2	0	0		0
ASW	BASE+HF+R+T+B	1.164	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.74285257
			0	0.20713	0.2	0	0		0
ASW	BASE+HF+FF+T+B	1.204	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.70678157
			0	0.20713	0.2	0	0		0
ASW	BASE+HF+P+T+B	2.211	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.57421915
			0	0.20713	0.2	0	0		0
ASW	BASE+R+FF+T+B	1.199	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.67174178
			0	0.20713	0.2	0	0		0
ASW	BASE+R+P+T+B	2.206	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.63511475
			0	0.20713	0.2	0	0		0
ASW	BASE+FF+P+T+B	2.246	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.56740064
			0	0.20713	0.2	0	0		0
ASW	BASE+R+T+B	1.159	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.60385535
			0	0.20713	0.2	0	0		0
ASW	BASE+FF+T+B	1.189	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.49316095
			0	0.20713	0.2	0	0		0
ASW	BASE+P+T+B	2.196	0.95	0.20713	0.8	0.1574188	0.76	0.76	0.31006645
			0	0.20713	0.2	0	0		0
ASW	BASE+HF+B	0.034	0.5	0.20713	0.6	0.062139	0.3	0.3	0.56855316
			0	0.20713	0.4	0	0		0
ASW	BASE+HF+R+B	0.029	0.5	0.20713	0.6	0.062139	0.3	0.3	0.66166878
			0	0.20713	0.4	0	0		0
ASW	BASE+HF+FF+B	0.069	0.5	0.20713	0.6	0.062139	0.3	0.3	0.62324845
			0	0.20713	0.4	0	0		0
ASW	BASE+HF+P+B	1.076	0.5	0.20713	0.6	0.062139	0.3	0.3	0.49303536
			0	0.20713	0.4	0	0		0
ASW	BASE+R+FF+B	0.064	0.5	0.20713	0.6	0.062139	0.3	0.3	0.58820865
			0	0.20713	0.4	0	0		0
ASW	BASE+R+P+B	1.071	0.5	0.20713	0.6	0.062139	0.3	0.3	0.55393096
			0	0.20713	0.4	0	0		0
ASW	BASE+FF+P+B	1.111	0.5	0.20713	0.6	0.062139	0.3	0.3	0.48386752
			0	0.20713	0.4	0	0		0
ASW	BASE+R+B	0.024	0.5	0.20713	0.6	0.062139	0.3	0.3	0.52267156
			0	0.20713	0.4	0	0		0
ASW	BASE+FF+B	0.054	0.5	0.20713	0.6	0.062139	0.3	0.3	0.40962782
			0	0.20713	0.4	0	0		0

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success[j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
ASW	BASE+P+B	1.061	0.5	0.20713	0.6	0.062139	0.3	0.3	0.22888266
			0	0.20713	0.4	0	0		0
RSTA	BASE	0	0	0.17249	0.1	0	0	0	
			0	0.17249	0.9	0	0		
RSTA	BASE+HF	0.03	1	0.17249	0.8	0.137992	0.8	0.8	
			0	0.17249	0.2	0	0		
RSTA	BASE+HF+R	0.025	0.98	0.17249	0.9	0.15213618	0.882	0.882	
			0	0.17249	0.1	0	0		
RSTA	BASE+HF+FF	0.065	0.92	0.17249	0.82	0.13012646	0.7544	0.7544	
			0	0.17249	0.18	0	0		
RSTA	BASE+HF+P	1.072	0.95	0.17249	0.85	0.13928568	0.8075	0.8075	
			0	0.17249	0.15	0	0		
RSTA	BASE+R+FF	0.06	0.85	0.17249	0.6	0.0879699	0.51	0.51	
			0	0.17249	0.4	0	0		
RSTA	BASE+R+P	1.067	0.88	0.17249	0.7	0.10625384	0.616	0.616	
			0	0.17249	0.3	0	0		
RSTA	BASE+FF+P	1.107	0.78	0.17249	0.68	0.0914887	0.5304	0.5304	
			0	0.17249	0.42	0	0		
RSTA	BASE+R	0.02	0.8	0.17249	0.4	0.0551968	0.32	0.32	
			0	0.17249	0.6	0	0		
RSTA	BASE+FF	0.05	0.5	0.17249	0.2	0.017249	0.1	0.1	
			0	0.17249	0.8	0		0	
RSTA	BASE+P	1.057	0.75	0.17249	0.6	0.0776205		0.45	0.45
			0	0.17249	0.4	0		0	
RSTA	BASE+T	2.274	0	0.17249	0.1	0		0	0
			0	0.17249	0.9	0		0	
RSTA	BASE+B	0.004	0	0.17249	0.1	0		0	0
			0	0.17249	0.9	0		0	
RSTA	BASE+T+B	1.139	0	0.17249	0.1	0		0	0
			0	0.17249	0.9	0		0	
RSTA	BASE+HF+T	2.304	1	0.17249	0.8	0.137992		0.8	0.8
			0	0.17249	0.2	0		0	
RSTA	BASE+HF+R+T	2.299	0.98	0.17249	0.9	0.15213618		0.882	0.882
			0	0.17249	0.1	0		0	
RSTA	BASE+HF+FF+T	2.339	0.92	0.17249	0.82	0.13012646		0.7544	0.7544
			0	0.17249	0.18	0		0	
RSTA	BASE+HF+P+T	3.346	0.95	0.17249	0.85	0.13928568		0.8075	0.8075
			0	0.17249	0.15	0		0	
RSTA	BASE+R+FF+T	2.334	0.85	0.17249	0.6	0.0879699		0.51	0.51
			0	0.17249	0.4	0		0	
RSTA	BASE+R+P+T	3.341	0.88	0.17249	0.7	0.10625384		0.616	0.616
			0	0.17249	0.3	0		0	
RSTA	BASE+FF+P+T	3.381	0.78	0.17249	0.68	0.0914887		0.5304	0.5304

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success|j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
			0	0.17249	0.42	0		0	
RSTA	BASE+R+T	2.294	0.8	0.17249	0.4	0.0551968		0.32	0.32
			0	0.17249	0.6	0		0	
RSTA	BASE+FF+T	2.324	0.5	0.17249	0.2	0.017249		0.1	0.1
			0	0.17249	0.8	0		0	
RSTA	BASE+P+T	3.31	0.75	0.17249	0.6	0.0776205		0.45	0.45
			0	0.17249	0.4	0		0	
RSTA	BASE+HF+T+B	1.169	1	0.17249	0.8	0.137992		0.8	0.8
			0	0.17249	0.2	0		0	
RSTA	BASE+HF+R+T+B	1.164	0.98	0.17249	0.9	0.15213618		0.882	0.882
			0	0.17249	0.1	0		0	
RSTA	BASE+HF+FF+T+B	1.204	0.92	0.17249	0.82	0.13012646		0.7544	0.7544
			0	0.17249	0.18	0		0	
RSTA	BASE+HF+P+T+B	2.211	0.95	0.17249	0.85	0.13928568		0.8075	0.8075
			0	0.17249	0.15	0		0	
RSTA	BASE+R+FF+T+B	1.199	0.85	0.17249	0.6	0.0879699		0.51	0.51
			0	0.17249	0.4	0		0	
RSTA	BASE+R+P+T+B	2.206	0.88	0.17249	0.7	0.10625384		0.616	0.616
			0	0.17249	0.3	0		0	
RSTA	BASE+FF+P+T+B	2.246	0.78	0.17249	0.68	0.0914887		0.5304	0.5304
			0	0.17249	0.42	0		0	
RSTA	BASE+R+T+B	1.159	0.8	0.17249	0.4	0.0551968		0.32	0.32
			0	0.17249	0.6	0		0	
RSTA	BASE+FF+T+B	1.189	0.5	0.17249	0.2	0.017249		0.1	0.1
			0	0.17249	0.8	0		0	
RSTA	BASE+P+T+B	2.196	0.75	0.17249	0.6	0.0776205		0.45	0.45
			0	0.17249	0.4	0		0	
RSTA	BASE+HF+B	0.034	1	0.17249	0.8	0.137992		0.8	0.8
			0	0.17249	0.2	0		0	
RSTA	BASE+HF+R+B	0.029	0.98	0.17249	0.9	0.15213618		0.882	0.882
			0	0.17249	0.1	0		0	
RSTA	BASE+HF+FF+B	0.069	0.92	0.17249	0.82	0.13012646		0.7544	0.7544
			0	0.17249	0.18	0		0	
RSTA	BASE+HF+P+B	1.076	0.95	0.17249	0.85	0.13928568		0.8075	0.8075
			0	0.17249	0.15	0		0	
RSTA	BASE+R+FF+B	0.064	0.85	0.17249	0.6	0.0879699		0.51	0.51
			0	0.17249	0.4	0		0	
RSTA	BASE+R+P+B	1.071	0.88	0.17249	0.7	0.10625384		0.616	0.616
			0	0.17249	0.3	0		0	
RSTA	BASE+FF+P+B	1.111	0.78	0.17249	0.68	0.0914887		0.5304	0.5304
			0	0.17249	0.42	0		0	
RSTA	BASE+R+B	0.024	0.8	0.17249	0.4	0.0551968		0.32	0.32
			0	0.17249	0.6	0		0	

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success[j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
RSTA	BASE+FF+B	0.054	0.5	0.17249	0.2	0.017249		0.1	0.1
			0	0.17249	0.8	0		0	
RSTA	BASE+P+B	1.061	0.75	0.17249	0.6	0.0776205		0.45	0.45
			0	0.17249	0.4	0		0	
NSFS	BASE	0	0	0.20376	0.4	0		0	0
			0	0.20376	0.6	0		0	
NSFS	BASE+HF	0.03	1	0.20376	0.85	0.173196		0.85	0.85
			0	0.20376	0.15	0		0	
NSFS	BASE+HF+R	0.025	0.95	0.20376	0.92	0.17808624		0.874	0.874
			0	0.20376	0.08	0		0	
NSFS	BASE+HF+FF	0.065	0.9	0.20376	0.88	0.16137792		0.792	0.792
			0	0.20376	0.12	0		0	
NSFS	BASE+HF+P	1.072	0.8	0.20376	0.85	0.1385568		0.68	0.68
			0	0.20376	0.15	0		0	
NSFS	BASE+R+FF	0.06	0.85	0.20376	0.7	0.1212372		0.595	0.595
			0	0.20376	0.3	0		0	
NSFS	BASE+R+P	1.067	0.68	0.20376	0.6	0.08313408		0.408	0.408
			0	0.20376	0.4	0		0	
NSFS	BASE+FF+P	1.107	0.65	0.20376	0.55	0.0728442		0.3575	0.3575
			0	0.20376	0.45	0		0	
NSFS	BASE+R	0.02	0.75	0.20376	0.6	0.091692		0.45	0.45
			0	0.20376	0.4	0		0	
NSFS	BASE+FF	0.05	0.65	0.20376	0.55	0.0728442		0.3575	0.3575
			0	0.20376	0.45	0		0	
NSFS	BASE+P	1.057	0	0.20376	0.4	0		0	0
			0	0.20376	0.6	0		0	
NSFS	BASE+T	2.274	0	0.20376	0.4	0		0	0
			0	0.20376	0.6	0		0	
NSFS	BASE+B	0.004	0	0.20376	0.4	0		0	0
			0	0.20376	0.6	0		0	
NSFS	BASE+T+B	1.139	0	0.20376	0.4	0		0	0
			0	0.20376	0.6	0		0	
NSFS	BASE+HF+T	2.304	1	0.20376	0.85	0.173196		0.85	0.85
			0	0.20376	0.15	0		0	
NSFS	BASE+HF+R+T	2.299	0.95	0.20376	0.92	0.17808624		0.874	0.874
			0	0.20376	0.08	0		0	
NSFS	BASE+HF+FF+T	2.339	0.9	0.20376	0.88	0.16137792		0.792	0.792
			0	0.20376	0.12	0		0	
NSFS	BASE+HF+P+T	3.346	0.8	0.20376	0.85	0.1385568		0.68	0.68
			0	0.20376	0.15	0		0	
NSFS	BASE+R+FF+T	2.334	0.85	0.20376	0.7	0.1212372		0.595	0.595
			0	0.20376	0.3	0		0	
NSFS	BASE+R+P+T	3.341	0.68	0.20376	0.6	0.08313408		0.408	0.408

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success|j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
			0	0.20376	0.4	0		0	
NSFS	BASE+FF+P+T	3.381	0.65	0.20376	0.55	0.0728442		0.3575	0.3575
			0	0.20376	0.45	0		0	
NSFS	BASE+R+T	2.294	0.75	0.20376	0.6	0.091692		0.45	0.45
			0	0.20376	0.4	0		0	
NSFS	BASE+FF+T	2.324	0.65	0.20376	0.55	0.0728442		0.3575	0.3575
			0	0.20376	0.45	0		0	
NSFS	BASE+P+T	3.31	0	0.20376	0.4	0		0	0
			0	0.20376	0.6	0		0	
NSFS	BASE+HF+T+B	1.169	1	0.20376	0.85	0.173196		0.85	0.85
			0	0.20376	0.15	0		0	
NSFS	BASE+HF+R+T+B	1.164	0.95	0.20376	0.92	0.17808624		0.874	0.874
			0	0.20376	0.08	0		0	
NSFS	BASE+HF+FF+T+B	1.204	0.9	0.20376	0.88	0.16137792		0.792	0.792
			0	0.20376	0.12	0		0	
NSFS	BASE+HF+P+T+B	2.211	0.8	0.20376	0.85	0.1385568		0.68	0.68
			0	0.20376	0.15	0		0	
NSFS	BASE+R+FF+T+B	1.199	0.85	0.20376	0.7	0.1212372		0.595	0.595
			0	0.20376	0.3	0		0	
NSFS	BASE+R+P+T+B	2.206	0.68	0.20376	0.6	0.08313408		0.408	0.408
			0	0.20376	0.4	0		0	
NSFS	BASE+FF+P+T+B	2.246	0.65	0.20376	0.55	0.0728442		0.3575	0.3575
			0	0.20376	0.45	0		0	
NSFS	BASE+R+T+B	1.159	0.75	0.20376	0.6	0.091692		0.45	0.45
			0	0.20376	0.4	0		0	
NSFS	BASE+FF+T+B	1.189	0.65	0.20376	0.55	0.0728442		0.3575	0.3575
			0	0.20376	0.45	0		0	
NSFS	BASE+P+T+B	2.196	0	0.20376	0.4	0		0	0
			0	0.20376	0.6	0		0	
NSFS	BASE+HF+B	0.034	1	0.20376	0.85	0.173196		0.85	0.85
			0	0.20376	0.15	0		0	
NSFS	BASE+HF+R+B	0.029	0.95	0.20376	0.92	0.17808624		0.874	0.874
			0	0.20376	0.08	0		0	
NSFS	BASE+HF+FF+B	0.069	0.9	0.20376	0.88	0.16137792		0.792	0.792
			0	0.20376	0.12	0		0	
NSFS	BASE+HF+P+B	1.076	0.8	0.20376	0.85	0.1385568		0.68	0.68
			0	0.20376	0.15	0		0	
NSFS	BASE+R+FF+B	0.064	0.85	0.20376	0.7	0.1212372		0.595	0.595
			0	0.20376	0.3	0		0	
NSFS	BASE+R+P+B	1.071	0.68	0.20376	0.6	0.08313408		0.408	0.408
			0	0.20376	0.4	0		0	
NSFS	BASE+FF+P+B	1.111	0.65	0.20376	0.55	0.0728442		0.3575	0.3575
			0	0.20376	0.45	0		0	

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success[j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
NSFS	BASE+R+B	0.024	0.75	0.20376	0.6	0.091692		0.45	0.45
			0	0.20376	0.4	0		0	
NSFS	BASE+FF+B	0.054	0.65	0.20376	0.55	0.0728442		0.3575	0.3575
			0	0.20376	0.45	0		0	
NSFS	BASE+P+B	1.061	0	0.20376	0.4	0		0	0
			0	0.20376	0.6	0		0	
CSAR	BASE	0	0	0.00166	0.5	0		0	0
			0	0.00166	0.5	0		0	
CSAR	BASE+HF	0.03	0.75	0.00166	0.6	0.000747		0.45	0.45
			0	0.00166	0.4	0		0	
CSAR	BASE+HF+R	0.025	1	0.00166	0.65	0.001079		0.65	0.65
			0	0.00166	0.35	0		0	
CSAR	BASE+HF+FF	0.065	0.85	0.00166	0.62	0.00087482		0.527	0.527
			0	0.00166	0.38	0		0	
CSAR	BASE+HF+P	1.072	0.72	0.00166	0.6	0.00071712		0.432	0.432
			0	0.00166	0.4	0		0	
CSAR	BASE+R+FF	0.06	0.75	0.00166	0.58	0.0007221		0.435	0.435
			0	0.00166	0.42	0		0	
CSAR	BASE+R+P	1.067	0.65	0.00166	0.55	0.00059345		0.3575	0.3575
			0	0.00166	0.45	0		0	
CSAR	BASE+FF+P	1.107	0.6	0.00166	0.52	0.00051792		0.312	0.312
			0	0.00166	0.48	0		0	
CSAR	BASE+R	0.02	0.7	0.00166	0.55	0.0006391		0.385	0.385
			0	0.00166	0.45	0		0	
CSAR	BASE+FF	0.05	0.6	0.00166	0.52	0.00051792		0.312	0.312
			0	0.00166	0.48	0		0	
CSAR	BASE+P	1.057	0	0.00166	0.5	0		0	0
			0	0.00166	0.5	0		0	
CSAR	BASE+T	2.274	0	0.00166	0.5	0		0	0
			0	0.00166	0.5	0		0	
CSAR	BASE+B	0.004	0	0.00166	0.5	0		0	0
			0	0.00166	0.5	0		0	
CSAR	BASE+T+B	1.139	0	0.00166	0.5	0		0	0
			0	0.00166	0.5	0		0	
CSAR	BASE+HF+T	2.304	0.75	0.00166	0.6	0.000747		0.45	0.45
			0	0.00166	0.4	0		0	
CSAR	BASE+HF+R+T	2.299	1	0.00166	0.65	0.001079		0.65	0.65
			0	0.00166	0.35	0		0	
CSAR	BASE+HF+FF+T	2.339	0.85	0.00166	0.62	0.00087482		0.527	0.527
			0	0.00166	0.38	0		0	
CSAR	BASE+HF+P+T	3.346	0.72	0.00166	0.6	0.00071712		0.432	0.432
			0	0.00166	0.4	0		0	
CSAR	BASE+R+FF+T	2.334	0.75	0.00166	0.58	0.0007221		0.435	0.435

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success|j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
			0	0.00166	0.42	0		0	
CSAR	BASE+R+P+T	3.341	0.65	0.00166	0.55	0.00059345		0.3575	0.3575
			0	0.00166	0.45	0		0	
CSAR	BASE+FF+P+T	3.381	0.6	0.00166	0.52	0.00051792		0.312	0.312
			0	0.00166	0.48	0		0	
CSAR	BASE+R+T	2.294	0.7	0.00166	0.55	0.0006391		0.385	0.385
			0	0.00166	0.45	0		0	
CSAR	BASE+FF+T	2.324	0.6	0.00166	0.52	0.00051792		0.312	0.312
			0	0.00166	0.48	0		0	
CSAR	BASE+P+T	3.31	0	0.00166	0.5	0		0	0
			0	0.00166	0.5	0		0	
CSAR	BASE+HF+T+B	1.169	0.75	0.00166	0.6	0.000747		0.45	0.45
			0	0.00166	0.4	0		0	
CSAR	BASE+HF+R+T+B	1.164	1	0.00166	0.65	0.001079		0.65	0.65
			0	0.00166	0.35	0		0	
CSAR	BASE+HF+FF+T+B	1.204	0.85	0.00166	0.62	0.00087482		0.527	0.527
			0	0.00166	0.38	0		0	
CSAR	BASE+HF+P+T+B	2.211	0.72	0.00166	0.6	0.00071712		0.432	0.432
			0	0.00166	0.4	0		0	
CSAR	BASE+R+FF+T+B	1.199	0.75	0.00166	0.58	0.0007221		0.435	0.435
			0	0.00166	0.42	0		0	
CSAR	BASE+R+P+T+B	2.206	0.65	0.00166	0.55	0.00059345		0.3575	0.3575
			0	0.00166	0.45	0		0	
CSAR	BASE+FF+P+T+B	2.246	0.6	0.00166	0.52	0.00051792		0.312	0.312
			0	0.00166	0.48	0		0	
CSAR	BASE+R+T+B	1.159	0.7	0.00166	0.55	0.0006391		0.385	0.385
			0	0.00166	0.45	0		0	
CSAR	BASE+FF+T+B	1.189	0.6	0.00166	0.52	0.00051792		0.312	0.312
			0	0.00166	0.48	0		0	
CSAR	BASE+P+T+B	2.196	0	0.00166	0.5	0		0	0
			0	0.00166	0.5	0		0	
CSAR	BASE+HF+B	0.034	0.75	0.00166	0.6	0.000747		0.45	0.45
			0	0.00166	0.4	0		0	
CSAR	BASE+HF+R+B	0.029	1	0.00166	0.65	0.001079		0.65	0.65
			0	0.00166	0.35	0		0	
CSAR	BASE+HF+FF+B	0.069	0.85	0.00166	0.62	0.00087482		0.527	0.527
			0	0.00166	0.38	0		0	
CSAR	BASE+HF+P+B	1.076	0.72	0.00166	0.6	0.00071712		0.432	0.432
			0	0.00166	0.4	0		0	
CSAR	BASE+R+FF+B	0.064	0.75	0.00166	0.58	0.0007221		0.435	0.435
			0	0.00166	0.42	0		0	
CSAR	BASE+R+P+B	1.071	0.65	0.00166	0.55	0.00059345		0.3575	0.3575
			0	0.00166	0.45	0		0	

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success|j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
CSAR	BASE+FF+P+B	1.111	0.6	0.00166	0.52	0.00051792		0.312	0.312
			0	0.00166	0.48	0		0	
CSAR	BASE+R+B	0.024	0.7	0.00166	0.55	0.0006391		0.385	0.385
			0	0.00166	0.45	0		0	
CSAR	BASE+FF+B	0.054	0.6	0.00166	0.52	0.00051792		0.312	0.312
			0	0.00166	0.48	0		0	
CSAR	BASE+P+B	1.061	0	0.00166	0.5	0		0	0
			0	0.00166	0.5	0		0	
MCM	BASE	0	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+HF	0.03	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+HF+R	0.025	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+HF+FF	0.065	0.5	0.15157	0.5	0.0378925		0.25	0.25
			0	0.15157	0.5	0		0	
MCM	BASE+HF+P	1.072	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+R+FF	0.06	0.5	0.15157	0.5	0.0378925		0.25	0.25
			0	0.15157	0.5	0		0	
MCM	BASE+R+P	1.067	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+FF+P	1.107	0.5	0.15157	0.5	0.0378925		0.25	0.25
			0	0.15157	0.5	0		0	
MCM	BASE+R	0.02	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+FF	0.05	0.5	0.15157	0.5	0.0378925		0.25	0.25
			0	0.15157	0.5	0		0	
MCM	BASE+P	1.057	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+T	2.274	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+B	0.004	0.98	0.15157	0.6	0.08912316		0.588	0.588
			0	0.15157	0.4	0		0	
MCM	BASE+T+B	1.139	0.9	0.15157	0.55	0.07502715		0.495	0.495
			0	0.15157	0.45	0		0	
MCM	BASE+HF+T	2.304	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+HF+R+T	2.299	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+HF+FF+T	2.339	0.5	0.15157	0.5	0.0378925		0.25	0.25
			0	0.15157	0.5	0		0	
MCM	BASE+HF+P+T	3.346	0	0.15157	0.5	0		0	0

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success|j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
			0	0.15157	0.5	0		0	
MCM	BASE+R+FF+T	2.334	0.5	0.15157	0.5	0.0378925		0.25	0.25
			0	0.15157	0.5	0		0	
MCM	BASE+R+P+T	3.341	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+FF+P+T	3.381	0.5	0.15157	0.5	0.0378925		0.25	0.25
			0	0.15157	0.5	0		0	
MCM	BASE+R+T	2.294	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+FF+T	2.324	0.5	0.15157	0.5	0.0378925		0.25	0.25
			0	0.15157	0.5	0		0	
MCM	BASE+P+T	3.31	0	0.15157	0.5	0		0	0
			0	0.15157	0.5	0		0	
MCM	BASE+HF+T+B	1.169	0.9	0.15157	0.55	0.07502715		0.495	0.495
			0	0.15157	0.45	0		0	
MCM	BASE+HF+R+T+B	1.164	0.9	0.15157	0.55	0.07502715		0.495	0.495
			0	0.15157	0.45	0		0	
MCM	BASE+HF+FF+T+B	1.204	0.95	0.15157	0.55	0.07919533		0.5225	0.5225
			0	0.15157	0.45	0		0	
MCM	BASE+HF+P+T+B	2.211	0.9	0.15157	0.55	0.07502715		0.495	0.495
			0	0.15157	0.45	0		0	
MCM	BASE+R+FF+T+B	1.199	0.95	0.15157	0.55	0.07919533		0.5225	0.5225
			0	0.15157	0.45	0		0	
MCM	BASE+R+P+T+B	2.206	0.9	0.15157	0.55	0.07502715		0.495	0.495
			0	0.15157	0.45	0		0	
MCM	BASE+FF+P+T+B	2.246	0.95	0.15157	0.55	0.07919533		0.5225	0.5225
			0	0.15157	0.45	0		0	
MCM	BASE+R+T+B	1.159	0.9	0.15157	0.55	0.07502715		0.495	0.495
			0	0.15157	0.45	0		0	
MCM	BASE+FF+T+B	1.189	0.95	0.15157	0.55	0.07919533		0.5225	0.5225
			0	0.15157	0.45	0		0	
MCM	BASE+P+T+B	2.196	0.9	0.15157	0.55	0.07502715		0.495	0.495
			0	0.15157	0.45	0		0	
MCM	BASE+HF+B	0.034	0.98	0.15157	0.6	0.08912316		0.588	0.588
			0	0.15157	0.4	0		0	
MCM	BASE+HF+R+B	0.029	0.98	0.15157	0.6	0.08912316		0.588	0.588
			0	0.15157	0.4	0		0	
MCM	BASE+HF+FF+B	0.069	1	0.15157	0.6	0.090942		0.6	0.6
			0	0.15157	0.4	0		0	
MCM	BASE+HF+P+B	1.076	0.98	0.15157	0.6	0.08912316		0.588	0.588
			0	0.15157	0.4	0		0	
MCM	BASE+R+FF+B	0.064	1	0.15157	0.6	0.090942		0.6	0.6
			0	0.15157	0.4	0		0	

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success[j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
MCM	BASE+R+P+B	1.071	0.98	0.15157	0.6	0.08912316		0.588	0.588
			0	0.15157	0.4	0		0	
MCM	BASE+FF+P+B	1.111	1	0.15157	0.6	0.090942		0.6	0.6
			0	0.15157	0.4	0		0	
MCM	BASE+R+B	0.024	0.98	0.15157	0.6	0.08912316		0.588	0.588
			0	0.15157	0.4	0		0	
MCM	BASE+FF+B	0.054	1	0.15157	0.6	0.090942		0.6	0.6
			0	0.15157	0.4	0		0	
MCM	BASE+P+B	1.061	0.98	0.15157	0.6	0.08912316		0.588	0.588
			0	0.15157	0.4	0		0	
Boarding	BASE	0	0	0.26339	0.8	0		0	0
			0	0.26339	0.2	0		0	
Boarding	BASE+HF	0.03	0.5	0.26339	0.8	0.105356		0.4	0.4
			0	0.26339	0.2	0		0	
Boarding	BASE+HF+R	0.025	0.8	0.26339	0.85	0.1791052		0.68	0.68
			0	0.26339	0.15	0		0	
Boarding	BASE+HF+FF	0.065	0.75	0.26339	0.9	0.17778825		0.675	0.675
			0	0.26339	0.1	0		0	
Boarding	BASE+HF+P	1.072	0.3	0.26339	0.8	0.0632136		0.24	0.24
			0	0.26339	0.2	0		0	
Boarding	BASE+R+FF	0.06	0.9	0.26339	0.95	0.22519845		0.855	0.855
			0	0.26339	0.05	0		0	
Boarding	BASE+R+P	1.067	0.95	0.26339	0.85	0.21268743		0.8075	0.8075
			0	0.26339	0.15	0		0	
Boarding	BASE+FF+P	1.107	0.7	0.26339	0.9	0.1659357		0.63	0.63
			0	0.26339	0.1	0		0	
Boarding	BASE+R	0.02	1	0.26339	0.85	0.2238815		0.85	0.85
			0	0.26339	0.15	0		0	
Boarding	BASE+FF	0.05	0.7	0.26339	0.9	0.1659357		0.63	0.63
			0	0.26339	0.1	0		0	
Boarding	BASE+P	1.057	0	0.26339	0.8	0		0	0
			0	0.26339	0.2	0		0	
Boarding	BASE+T	2.274	0	0.26339	0.8	0		0	0
			0	0.26339	0.2	0		0	
Boarding	BASE+B	0.004	0	0.26339	0.8	0		0	0
			0	0.26339	0.2	0		0	
Boarding	BASE+T+B	1.139	0	0.26339	0.8	0		0	0
			0	0.26339	0.2	0		0	
Boarding	BASE+HF+T	2.304	0.5	0.26339	0.8	0.105356		0.4	0.4
			0	0.26339	0.2	0		0	
Boarding	BASE+HF+R+T	2.299	0.8	0.26339	0.85	0.1791052		0.68	0.68
			0	0.26339	0.15	0		0	
Boarding	BASE+HF+FF+T	2.339	0.75	0.26339	0.9	0.17778825		0.675	0.675

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success|j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
			0	0.26339	0.1	0		0	
Boarding	BASE+HF+P+T	3.346	0.3	0.26339	0.8	0.0632136		0.24	0.24
			0	0.26339	0.2	0		0	
Boarding	BASE+R+FF+T	2.334	0.9	0.26339	0.95	0.22519845		0.855	0.855
			0	0.26339	0.05	0		0	
Boarding	BASE+R+P+T	3.341	0.95	0.26339	0.85	0.21268743		0.8075	0.8075
			0	0.26339	0.15	0		0	
Boarding	BASE+FF+P+T	3.381	0.7	0.26339	0.9	0.1659357		0.63	0.63
			0	0.26339	0.1	0		0	
Boarding	BASE+R+T	2.294	1	0.26339	0.85	0.2238815		0.85	0.85
			0	0.26339	0.15	0		0	
Boarding	BASE+FF+T	2.324	0.7	0.26339	0.9	0.1659357		0.63	0.63
			0	0.26339	0.1	0		0	
Boarding	BASE+P+T	3.31	0	0.26339	0.8	0		0	0
			0	0.26339	0.2	0		0	
Boarding	BASE+HF+T+B	1.169	0.5	0.26339	0.8	0.105356		0.4	0.4
			0	0.26339	0.2	0		0	
Boarding	BASE+HF+R+T+B	1.164	0.8	0.26339	0.85	0.1791052		0.68	0.68
			0	0.26339	0.15	0		0	
Boarding	BASE+HF+FF+T+B	1.204	0.75	0.26339	0.9	0.17778825		0.675	0.675
			0	0.26339	0.1	0		0	
Boarding	BASE+HF+P+T+B	2.211	0.3	0.26339	0.8	0.0632136		0.24	0.24
			0	0.26339	0.2	0		0	
Boarding	BASE+R+FF+T+B	1.199	0.9	0.26339	0.95	0.22519845		0.855	0.855
			0	0.26339	0.05	0		0	
Boarding	BASE+R+P+T+B	2.206	0.95	0.26339	0.85	0.21268743		0.8075	0.8075
			0	0.26339	0.15	0		0	
Boarding	BASE+FF+P+T+B	2.246	0.7	0.26339	0.9	0.1659357		0.63	0.63
			0	0.26339	0.1	0		0	
Boarding	BASE+R+T+B	1.159	1	0.26339	0.85	0.2238815		0.85	0.85
			0	0.26339	0.15	0		0	
Boarding	BASE+FF+T+B	1.189	0.7	0.26339	0.9	0.1659357		0.63	0.63
			0	0.26339	0.1	0		0	
Boarding	BASE+P+T+B	2.196	0	0.26339	0.8	0		0	0
			0	0.26339	0.2	0		0	
Boarding	BASE+HF+B	0.034	0.5	0.26339	0.8	0.105356		0.4	0.4
			0	0.26339	0.2	0		0	
Boarding	BASE+HF+R+B	0.029	0.8	0.26339	0.85	0.1791052		0.68	0.68
			0	0.26339	0.15	0		0	
Boarding	BASE+HF+FF+B	0.069	0.75	0.26339	0.9	0.17778825		0.675	0.675
			0	0.26339	0.1	0		0	
Boarding	BASE+HF+P+B	1.076	0.3	0.26339	0.8	0.0632136		0.24	0.24
			0	0.26339	0.2	0		0	

Table D2. Tabular Decision Tree

Mission i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	Normalized p(i)	p(success[j,i)	col4*col5* col6	E[con fig]	Pre-Config Utility	Config u[config]
Boarding	BASE+R+FF+B	0.064	0.9	0.26339	0.95	0.22519845		0.855	0.855
			0	0.26339	0.05	0		0	
Boarding	BASE+R+P+B	1.071	0.95	0.26339	0.85	0.21268743		0.8075	0.8075
			0	0.26339	0.15	0		0	
Boarding	BASE+FF+P+B	1.111	0.7	0.26339	0.9	0.1659357		0.63	0.63
			0	0.26339	0.1	0		0	
Boarding	BASE+R+B	0.024	1	0.26339	0.85	0.2238815		0.85	0.85
			0	0.26339	0.15	0		0	
Boarding	BASE+FF+B	0.054	0.7	0.26339	0.9	0.1659357		0.63	0.63
			0	0.26339	0.1	0		0	
Boarding	BASE+P+B	1.061	0	0.26339	0.8	0		0	0
			0	0.26339	0.2	0		0	

Table D3 in this appendix lists the values as shown in **Table D2** for the non-weapon missions. These missions were not included in the model, but the calculations are provided for completeness.The columns are explained below:

- Column 1: **Mission, i** ... The three missions assigned to the SH–60B not used in the thesis model (ASST, ECM, Utility).
- Column 2: **Helicopter Configuration, j** ... The 44 weapon configurations listed for each of the missions. **Appendix B** lists the applicable mission-configuration combinations.
- Column 3: **Config. Cost (million $)** ... The configuration cost in millions of dollars as determined from Reference 10 and 11, and discussed in **Chapter IV** on page 44. **Table D4** in this appendix lists the costs for each of the 44 configurations.
- Column 4: **Utility, u(r)** ... The utility of each mission and configuration combination is shown in **Appendix C** and summarized in **Table 5** on page 41.
- Column 5: **p(i)** ... The probability of being assigned a particular mission. This value was determined by uniform random number generator whose values are listed in **Table D4** of this appendix. These probabilities are based on the nine missions the SH–60B is assigned.
- Column 6: **p(success| j, i)** ... These are the probabilities of mission success (the labeled mission-configuration row) and mission failure (the unlabeled mission-configuration row) for a given mission and configuration. These values are subjective assignments based on the perceived mission and configuration success by the author.
- Column 7: **col 4×col 5×col 6** ... The product of columns 4, 5, and 6 and used in column 8 calculations.
- Column 8: **E[config]** ... The expected value of each configuration, which is determined by summing the expected value of each configuration type over all the missions. The **col 4×col 5×col 6** column was the source for the expected values of the configurations.
- Column 9: **Pre–Config. Utility** ... The configuration utility calculated for each possible outcome. Column 4 times column 6 yields this result.

Table D3. Tabular Decision Tree (non–weapon missions)

Mission, i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	p(i)	p(success|j,i)	col4*col5* col6	E[config]	Pre-Config Utility
ASST	BASE	0	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF	0.03	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+R	0.025	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+FF	0.065	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+P	1.072	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+FF	0.06	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+P	1.067	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+FF+P	1.107	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R	0.02	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+FF	0.05	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+P	1.057	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+T	2.274	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+B	0.004	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+T+B	1.139	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+T	2.304	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+R+T	2.299	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+FF+T	2.339	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+P+T	3.346	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+FF+T	2.334	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+P+T	3.341	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+FF+P+T	3.381	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+T	2.294	0	0.10168	0.98	0	0	0

Table D3. Tabular Decision Tree (non–weapon missions)

Mission, i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	p(i)	p(success|j,i)	col4*col5* col6	E[config]	Pre-Config Utility
			0	0.10168	0.02	0	0	
ASST	BASE+FF+T	2.324	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+P+T	3.31	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+T+B	1.169	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+R+T+B	1.164	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+FF+T+B	1.204	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+P+T+B	2.211	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+FF+T+B	1.199	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+P+T+B	2.206	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+FF+P+T+B	2.246	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+T+B	1.159	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+FF+T+B	1.189	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+P+T+B	2.196	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+B	0.034	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+R+B	0.029	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+FF+B	0.069	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+HF+P+B	1.076	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+FF+B	0.064	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+P+B	1.071	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+FF+P+B	1.111	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+R+B	0.024	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ASST	BASE+FF+B	0.054	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	

Table D3. Tabular Decision Tree (non–weapon missions)

Mission, i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	p(i)	p(success|j,i)	col4*col5* col6	E[config]	Pre-Config Utility
ASST	BASE+P+B	1.061	0	0.10168	0.98	0	0	0
			0	0.10168	0.02	0	0	
ECM	BASE	0	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF	0.03	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+R	0.025	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+FF	0.065	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+P	1.072	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+FF	0.06	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+P	1.067	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+FF+P	1.107	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R	0.02	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+FF	0.05	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+P	1.057	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+T	2.274	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+B	0.004	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+T+B	1.139	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+T	2.304	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+R+T	2.299	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+FF+T	2.339	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+P+T	3.346	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+FF+T	2.334	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+P+T	3.341	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+FF+P+T	3.381	0	0.00423	0.6	0	0	0

Table D3. Tabular Decision Tree (non–weapon missions)

Mission, i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	p(i)	p(success|j,i)	col4*col5* col6	E[config]	Pre-Config Utility
			0	0.00423	0.4	0	0	
ECM	BASE+R+T	2.294	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+FF+T	2.324	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+P+T	3.31	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+T+B	1.169	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+R+T+B	1.164	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+FF+T+B	1.204	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+P+T+B	2.211	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+FF+T+B	1.199	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+P+T+B	2.206	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+FF+P+T+B	2.246	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+T+B	1.159	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+FF+T+B	1.189	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+P+T+B	2.196	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+B	0.034	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+R+B	0.029	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+FF+B	0.069	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+HF+P+B	1.076	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+FF+B	0.064	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+P+B	1.071	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+FF+P+B	1.111	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+R+B	0.024	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	

Table D3. Tabular Decision Tree (non–weapon missions)

Mission, i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	p(i)	p(success|j,i)	col4*col5* col6	E[config]	Pre-Config Utility
ECM	BASE+FF+B	0.054	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
ECM	BASE+P+B	1.061	0	0.00423	0.6	0	0	0
			0	0.00423	0.4	0	0	
Other	BASE	0	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF	0.03	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+R	0.025	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+FF	0.065	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+P	1.072	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+FF	0.06	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+P	1.067	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+FF+P	1.107	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R	0.02	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+FF	0.05	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+P	1.057	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+T	2.274	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+B	0.004	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+T+B	1.139	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+T	2.304	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+R+T	2.299	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+FF+T	2.339	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+P+T	3.346	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+FF+T	2.334	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+P+T	3.341	0	0.18225	0.7	0	0	0

Table D3. Tabular Decision Tree (non–weapon missions)

Mission, i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	p(i)	p(success|j,i)	col4*col5* col6	E[config]	Pre-Config Utility
			0	0.18225	0.3	0	0	
Other	BASE+FF+P+T	3.381	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+T	2.294	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+FF+T	2.324	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+P+T	3.31	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+T+B	1.169	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+R+T+B	1.164	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+FF+T+B	1.204	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+P+T+B	2.211	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+FF+T+B	1.199	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+P+T+B	2.206	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+FF+P+T+B	2.246	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+T+B	1.159	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+FF+T+B	1.189	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+P+T+B	2.196	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+B	0.034	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+R+B	0.029	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+FF+B	0.069	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+HF+P+B	1.076	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+FF+B	0.064	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+R+P+B	1.071	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+FF+P+B	1.111	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	

Table D3. Tabular Decision Tree (non–weapon missions)

Mission, i	Helicopter Configuration, j	Config Cost (million $)	Utility u(r)	p(i)	p(success|j,i)	col4*col5* col6	E[config]	Pre-Config Utility
Other	BASE+R+B	0.024	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+FF+B	0.054	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	
Other	BASE+P+B	1.061	0	0.18225	0.7	0	0	0
			0	0.18225	0.3	0	0	

Table D4 lists the perfect information data, the uniform random numbers used to compute the mission assignment probabilities, and the coordinates, extracted from **Table D3**, used to plot the Pareto Frontier. The columns are discussed below:

- Column 1: The mission associated with each row
- Column 2: The maximum value of column 10 of **Table D3** for each mission type (one maximum value for each mission).
- Column 3: The product of p(i)×max{u(j)} for each mission type (the individual elements of the mission expected value).
- Column4: The expected value of all missions (the sum of column 2).
- Column 5: A spacer column.
- Column 6: The row label for mission probabilities and column sums.
- Column 7: Nine uniform random numbers between 0.5 and 9.5. Sum of all nine values.
- Column8: The uniform probability values of a mission, determined by the column 6 row values divided by the column sum.
- Column 9: Normalized mission probabilities. Value determined by dividing column 7 values by one minus the "sum of the no weapon missions p(i)'s," listed at the bottom of the table.

Table D4. Calculations and Data Values for Decision Problem

Perfect Information Calculations					**Uniform Random**		
mission	**Max{u(config)}**	**p(i) * max{u(j)}**	**E[Mission}**	**p(mission)**	**Number Generator**	**p(i**	**Normalized p(i)**
asw	0.9	0.1864	0.8339	p(asw)	0.6886	0.14744	0.20713
rsta	0.882	0.1521		p(rsta)	0.57344	0.12279	0.17249
nsfs	0.874	0.1781		p(nsfs)	0.67739	0.14504	0.20376
csar	0.65	0.0011		p(csar)	0.00553	0.00118	0.00166
mcm	0.6	0.0909		p(mcm)	0.50388	0.10789	0.15157
boarding	0.855	0.2252		p(boarding)	0.87564	0.18749	0.26339
asst	0	0		p(asst)	0.47487	0.10168	no weapons
ecm	0	0		p(ecm)	0.01974	0.00423	no weapons
other	0	0		p(other)	0.85116	0.18225	no weapons
				Column Sums:	4.67025	1	1
		Sum of NO weapon mission's (p(i):			0.28816		

Table D5 lists the data points used to construct the Pareto Frontier graph. The following describes each column:

- Column 1: The expected value of each feasible weapons configuration. Column 8 of **Table D2**.
- Column 2: The cost of each configuration. Column 3 of **Table D2**.

Table D5. Pareto Frontier Data Points

Expected Value of configuration	Configuration Cost
0	0
0.4173	0.03
0.5104	0.025
0.5081	0.065
0.3418	1.072
0.473	0.06
0.4027	1.067
0.3687	1.107
0.3714	0.02
0.2944	0.05
0.0776	1.057
0.1864	2.274
0.1513	0.004
0.2324	1.139
0.6037	2.304
0.6968	2.299
0.6945	2.339
0.5282	3.346
0.6594	2.334
0.5891	3.341
0.5551	3.381
0.5578	2.294
0.4809	2.324
0.264	3.31
0.6497	1.169

Table D5. Pareto Frontier Data Points

Expected Value of configuration	Configuration Cost
0.7429	1.164
0.7068	1.204
0.5742	2.211
0.6717	1.199
0.6351	2.206
0.5674	2.246
0.6039	1.159
0.4932	1.189
0.3101	2.196
0.5686	0.034
0.6617	0.029
0.6232	0.069
0.493	1.076
0.5882	0.064
0.5539	1.071
0.4839	1.111
0.5227	0.024
0.4096	0.054
0.2289	1.061

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